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OIL LAND
DEVELOPMENT AND VALUATION

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BY

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PREFACE

The rapidly increasing demand for petroleum has led to more careful methods of mining, aiming to obtain the maximum production. The entire structure of the oil industry finally rests upon the productive property which furnishes the crude oil. It is therefore necessary that all possible precautions, evolved from past experience, be applied to the construction and maintenance of the wells tapping the original source of supply.

The oil industry is too complex and highly developed to be treated thoroughly in a single volume or by a single author. This book aims to outline only the steps necessary for the full and proper development of lands which have already been determined to be oil-bearing. It is hoped that the subject matter herein treated will be valuable to all who are concerned in or responsible for oil field operations.

The best methods of oil land development require information furnished by both geological and engineering investigations. The information herewith presented is based upon some ten years of such investigations, a portion of which were made while administering the oil and gas conservation laws of the State of California.

The operating conditions in the oil fields of California are of great diversity and embrace the general conditions obtaining elsewhere. Most of the obstacles encountered in the various fields of the world occur in some California field. The general principles involved in oil production, herein set forth, are applicable to all oil fields.

The necessity for careful and systematic development and conservation of oil deposits has not been generally recognized. While the details of planning and inspecting development work will fall to the lot of the engineering specialist, it is necessary that the land owner or the business executive shall have a general

knowledge of them in order that their relative importance may be recognized. This book is written with the idea of presenting a broad view of oil land development and at the same time giving details and references sufficient for the use of the specialist.

The oil industry is undoubtedly entering a period during which methods of production will be most carefully studied and improved. If this volume aids the advancement of the industry, in some small measure, the expectation of the author will be met.

For helpful suggestions and criticism the author is specially indebted to Messrs. R. D. Bush, J. B. Case, R. E. Collom, A. L. Coombs, Chester Naramore and William A. Williams.

R. P. McLaughlin.

San Francisco, Cal.,
December, 1920.

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OIL LAND DEVELOPMENT
AND
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CHAPTER I

DEVELOPMENT PROGRAM

Location and Spacing of Wells.—The first problem which presents itself, when development of a tract of oil land begins, is the location of the first well and the determination of the area which individual wells shall be expected to drain. Frequently, the operator is allowed no choice in these matters, due to the fact that wells have already been drilled or started on neighboring properties so close to the boundary lines that it becomes imperative to drill "off-set" wells in order to prevent the neighboring wells from obtaining an undue proportion of oil. A property can be more profitably operated if agreements with neighbors are obtained so as to obviate competitive drilling, which usually entails an excessive number of wells profitable to neither party. The present discussion cannot cover all the phases involved in "line drilling" and agreements between neighbors, but will deal with general principles. These principles should be considered by a single operator holding a large property, and should be the basis of consideration between neighboring operators.

The first well on a property should be drilled at a location giving promise of yielding the greatest amount of oil and furnishing information for guiding subsequent drilling outward towards the non-productive margin or limit. Where there are no wells in the immediate locality the first well will have to be located purely upon such evidence as is afforded by a geological study of the ground surface of the region. Consideration of the subject

of purely geological investigations is beyond the province of this book. If there are producing wells in the locality, their physical condition and productivity will furnish evidence which may outweigh that afforded by mere geological study of the ground surface. The following chapters set forth the manner in which evidence afforded by well drilling can be assembled and studied.

The distance between wells should be determined so as to extract most profitably the oil under a tract of land. This subject apparently has not been systematically studied, as frequent instances exist where operators have made unnecessary expenditure by drilling an excessive number of wells. No definite rule can be established which will meet all conditions. However, consideration of some of the underlying principles, together with such facts as are at present available, should lead to further study on the part of operators, and would result in saving very considerable sums of money.

An example of unnecessary expenditure is afforded by the production records of four wells shown in Fig. 1.

It will be noted that as each new well was completed there was a marked decline in the production of wells already completed; and that each new well drew much of its production from natural reservoirs previously supplying the adjoining wells. One well, or at most two wells, would doubtless have supplied as much oil as the four, which were actually drilled at a cost of about $50,000 each. Needless expense would have been avoided by regular observation and comparison of the production records of each of the wells. It will also be noted that the record of the total production of the entire group of wells leads, of itself, to the conclusion that each additional well was a benefit to the property, but the records of individual wells show that the utmost benefit was not being obtained.

The most profitable spacing of wells falls between two extreme limits, each of which would, of course, in practice be an absurdity. The limits depend upon the desired rapidity of production. The quickest way of removing all possible oil from the ground would be to drill wells as closely as possible to each other, in

which event the output of each well would, in most cases, not repay its first cost. The opposite extreme would follow the assumption that one well would, if given time enough, drain an entire pool. Physical conditions, such as obstructed channels, due to close grained rock or precipitated residue, eliminate such an assump-

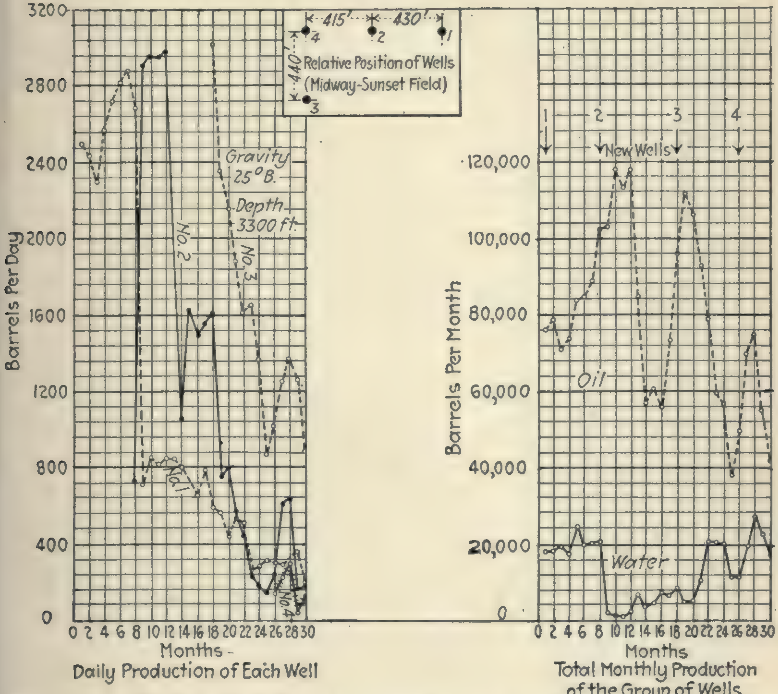


Fig. 1.—Example of wells drilled too closely and thereby draining each other's territory.

tion, even though it were financially permissible to wait indefinitely for production.

The cost of drilling wells increases with their depth and, therefore, where other productive conditions are equal, deeper fields will, in general, require wider spacing of wells.

Some idea of the proper distance between wells can no doubt

be obtained in each field by trial and observation. Such a practice will be only approximate, but where careful observation shows that new wells are draining old ones the distance should be increased.

A study of maps of American oil fields shows that boundary lines have usually received first attention and that spacing of wells has, apparently, not been given much consideration. A distance of 440 ft. between wells, or 4.45 acres per well, seems to be very common in many American fields. Such spacing is probably due to the fact that legal subdivisions of land, by fractional parts of sections, are conveniently covered by such distances.

A definite and arbitrary rule for spacing wells may be useful until observation has furnished a better one. Such information as is available suggests that depth shall be the controlling factor with wells 440 ft. apart in 1000 ft. territory (4.45 acres per well) and the distance increased up to 660 ft. in 3000 feet territory (10 acres per well). Such a rule is suggested for fields where geological conditions are comparatively simple; that is, stratified beds only slightly disturbed. Conditions in fields influenced by salt domes, igneous intrusions or pronounced folding may require other plans. However, even these special conditions would seem to warrant systematic study of the behavior of neighboring wells.

The first well completed in a locality frequently establishes drainage conditions which are most favorable for production, and these conditions are not easily overcome by later wells.

Wells are ordinarily located in rows running at right angles to each other. Such an arrangement allots a square of land to be drained by each well. A more even division of the area would stagger the wells so that each would be at the center of a hexagonal area. Such a refinement, however, would appear superfluous where it is not definitely known how far apart the individual wells should be.[1]

[1] L. G. Huntley: Possible Causes of the Decline of Oil Wells and Suggested Methods of Prolonging Yield. Technical Paper No. 51, U. S. Bureau of Mines, 1913.

Investigation of Productive Formations to be Developed.—A given tract of land frequently contains several separate strata of oil or gas bearing formation. One of the early steps in a development program is to determine the position, extent and productiveness of the several strata. Such a determination not only serves the purpose of a mere inventory of assets but is also necessary in order that a particular stratum may be exploited without damage or waste to the others. Besides avoiding waste or damage to the underground deposits, a preliminary study of their relative positions makes possible a more economical plan for their development.

Underlying or lower strata of productive formations are frequently sought for by deep prospect wells after an upper stratum has been partly or wholly developed. Such a procedure appears so simple and logical as to require no particular study or consideration. However, in many instances, careful study has shown that such development work failed to disclose the most easily accessible deposits.

In the Elk Hills field of California, a most productive gas zone, having a rock pressure of about 800 lbs. per sq. in., and yielding from 30,000,000 to 100,000,000 cu. ft. per well per day, was actually drilled through without recognition by the drilling crew who followed the ordinary observation practice. A subsequent geological study, based largely upon logs of wells in the locality, led to the actual discovery and development of the gas. When drilling was stopped at a designated depth and the well tested by being bailed dry, the gas flowed so forcibly that considerable trouble was involved in capping the well.[1]

In the Coyote Hills field of California, a very productive oil formation (one well yielding 10,000 bbl. daily) was drilled through by some 85 wells. Oil was noted in only 11 of the well logs. Systematic study of the logs and drilling conditions led to setting casing above the upper stratum, drilling short distances and test-

[1] Fourth Annual Report, State Oil & Gas Supervisor of California. May, 1919. pp. 4–8.

ing productivity by bailing the well. This procedure led to the discovery. Many similar instances have been noted.

In the Goose Creek field of Texas at least one instance was noted where a well became a very profitable producer through an accidental perforation of the casing about 1000 ft. above the supposed productive formation.

In the Somerset field of Texas early drilling generally penetrated the Taylor formation only a short distance and wells produced about 10 or 15 bbls. of oil daily. A systematic study of the situation led to a departure from previous practice and the formation was opened to a depth of about 200 ft. with the result that the daily production was increased to 50 or 75 bbls. per well.

Valuable natural gas reservoirs have in past years been wastefully depleted because the operators desired only to reach underlying oil formations. Systematic studies of geological and operating conditions have led to state legislation which aims to segregate and protect all valuable oil and gas bearing strata. The work of the U. S. Bureau of Mines in the Oklahoma fields is an excellent example of the value of guiding underground development by preliminary scientific study.[1]

Rate of Development.—Some plan governing the rate of development is necessary when work starts. That the subject is of importance is shown by the fact that leases of oil land frequently specify that a certain number of wells shall be drilled each year.

The rate of development will frequently be entirely governed by such facts as the price of oil and the drilling activity on adjoining lands. There are, however, some general features which may also present themselves for consideration.

The promptness with which a tract of oil land is developed, by drilling wells, governs the speed with which the invested funds are returned.

The length of time consumed in drilling each well will, of course, have great influence on a plan of development. At a

[1] J. O. Lewis and Wm. F. McMurray: The Use of Mud-laden Fluid in Oil and Gas Wells. U. S. Bureau of Mines, *Bulletin* 134, 1916.

locality where a well can be completed in a few days, it will be quite natural to drill the property completely in a short time. Where a year or more is necessary to finish a well, fast development would be discouraged.

Cost of operating a producing property should also be considered in planning its development. The cost of operating several completed wells is usually not much greater than that of

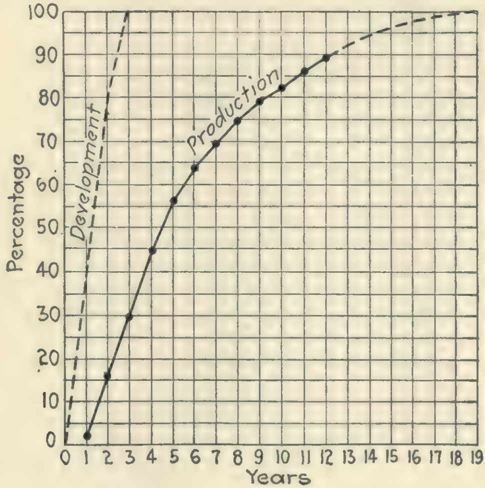


FIG. 2.—Example of prompt development of land and speedy production of oil. (Same property as shown in Fig. 46.)

operating one well. The largest number of wells which can be operated at this base or minimum cost will, of course, entail the smallest operating cost per well or per barrel of oil. Such a number of wells might, therefore, be the goal for one stage of development, and additional wells might be completed by similar groups.

Where it is desirable to estimate the relation between rate of development and rate of production, it may be possible to use past records of neighboring properties and fields somewhat as in Figs. 2 and 3.

Figure 2 shows the result of comparatively rapid development, the land having been completely drilled in three years. One-half of the probable total ultimate yield was thereby produced in a little over five years. A more complete description of this property accompanies Fig. 46 which shows its production record.

Figure 3 shows the result of comparatively slow, development, the maximum number of wells having been almost completed in about 20 years. One-half of the total ultimate yield was thereby

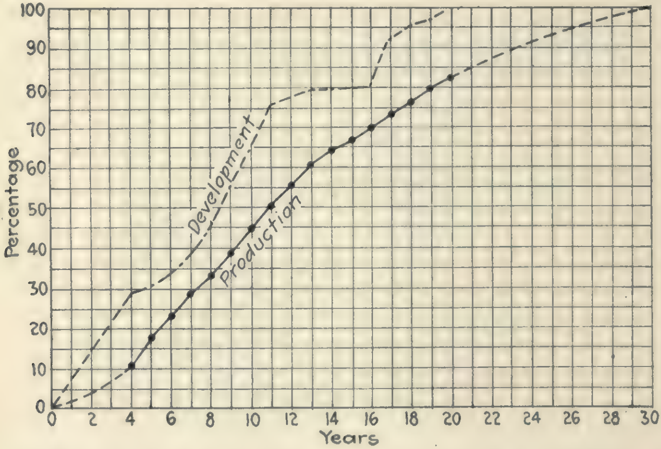


FIG. 3.—Example of slow development of land and slow production of oil. (Same field as shown in Fig. 47.)

produced in 11 years. Further description of this field accompanies Fig. 47, which is a graphic record of development and production.

Methods of Well Drilling.—Two courses are open in the drilling of a tract of land. The wells may be drilled either by a contractor or by the operator. The advantage of drilling by contract is that it obviates the necessity of building up an organization to carry on the work, and also relieves the operator from investing in drilling machinery.

A great disadvantage of the contract method, in some cases,

is that little or no control over details is left to the operator. A contract is usually let at a fixed price per foot, payable when a certain agreed stage of completion is reached. Sometimes the contract goes no further than setting casing at a certain depth, with water shut off, while in other cases the well must be turned over to the owner as a producer. In either event, the owner has little opportunity to make tests or detailed observations which might delay drilling. Sometimes it is quite necessary, if the property is to be thoroughly exploited, to conduct various tests as successive strata are penetrated.

Two kinds of tools are available for oil well drilling; namely, cable or rotary. The nature of the strata overlying the oil deposits will frequently determine which type of tools must be used.

Rotary tools are specially adapted to soft ground which would cave unless the hole were filled or plastered with mud. Rotary tools are able to work against high pressures of gas or liquid which could scarcely be handled with cable tools.

Cable tools are specially suited to hard ground in which the hole stands open without difficulty.

There are some fields where the nature of the ground permits the use of both kinds of tools. In such fields, the relative advantages and disadvantages of the two types must be considered. There is a division of opinion as to some of the claimed advantages. The following points, however, have been quite definitely settled. The advantages of rotary tools are speed and cheapness of drilling. Some recent comparisons in California at a depth of 2500 ft. show a cost of \$20 per foot with cable tools as against \$13 for rotary. The saving was due to the fact that more speed was attained and less casing was necessary with rotary tools. Labor cost per day on cable tools was \$46.50 as against \$96.00 with rotary tools.

One of the principal disadvantages in the use of rotary tools is that a correct record of formations can not be obtained unless unusual care is exercised, which results in a considerable loss of time. Instances are numerous where rotary tools have passed

through very productive oil and gas formations without their value being recognized. It is frequently advisable to use rotary tools to set the casing a short distance above the oil bearing formations, where their positions are accurately known, and then finish the well with cable tools, so that full opportunity may be given to recognize all productive formations as they are encountered. Finishing a well with cable tools also keeps unnecessary mud from clogging the productive formations. Water bearing formations should be recognized as drilling progresses if wells are to be properly completed. Cable tools make this possible. Rotary tools are generally unsuitable for thorough prospecting work.

CHAPTER II

DRILLING OF OIL WELLS

The drilling of oil wells is a branch of skilled labor which, like all other trades, can be learned only by the actual doing. The tools for carrying on drilling work are supplied by manufacturing concerns who are alive to the necessity of providing improved devices based upon the inventive genius of many well drillers. Our purpose is not to recount the duties of a skilled driller, nor to summarize the information contained in the many complete and excellent catalogs of oil well machinery, but rather to present general principles conducive to most efficient operations.

The most effective use of skilled workmen and good tools requires planning, and inspection. This procedure applies to all construction work, whether it be that of a tall building or of a deep oil well. This chapter aims to present the general features involved in planning and inspecting the drilling of oil wells.

Geological and Physical Conditions Affecting a Well.—The two general conditions which govern the productiveness and value of an oil well are the natural or geological conditions of the locality, and the artificial or physical conditions of the well in question and its neighbors. It would be impractical to enumerate all of the various combinations of conditions here; however, the following sketches illustrate some conditions which are frequently encountered.

The sketches herewith presented particularly emphasize the flooding of oil wells by water, which is a great problem in many fields. The first five sketches (Figs. 4–8) illustrate the damage resulting from physical conditions in the wells themselves while the remaining sketches (Figs. 9–13) illustrate the damage due to failure of development work to conform to geological conditions.

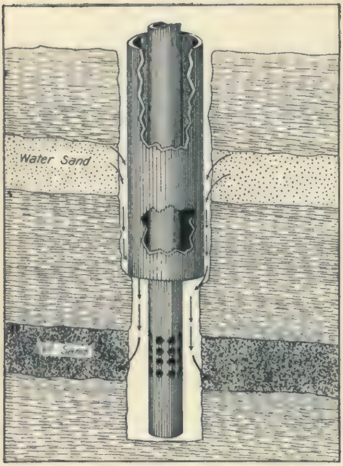


FIG. 4.—Sketch showing entrance of water into oil sand due to imperfect seating of casing and to lack of cement around bottom of outer casing.

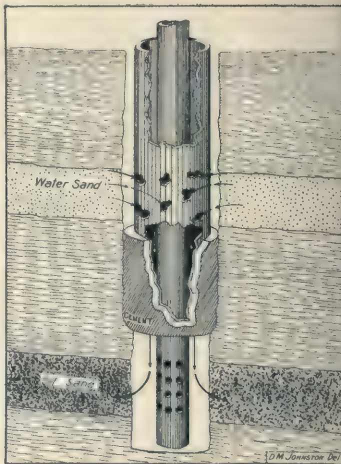


FIG. 5.—Sketch showing entrance of water due to holes eaten in casing by chemical action.

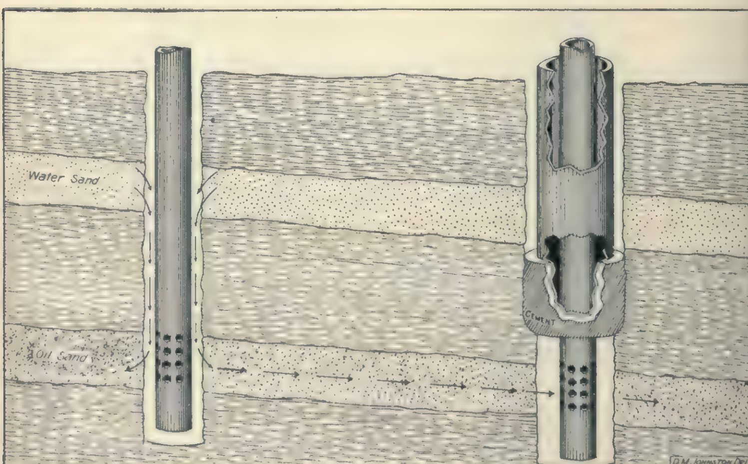


FIG. 6.—Sketch showing entrance of water into oil sand and its migration to a properly drilled well. Due to use of only one string of casing in first well.

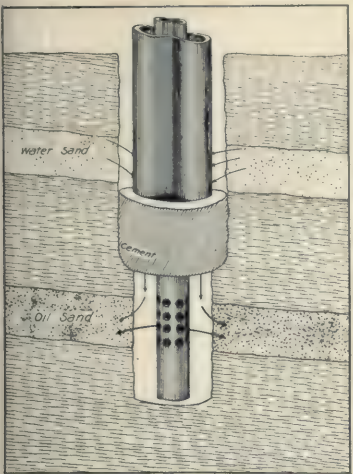


FIG. 7.—Sketch showing entrance of water into oil sand due to collapse of casing.

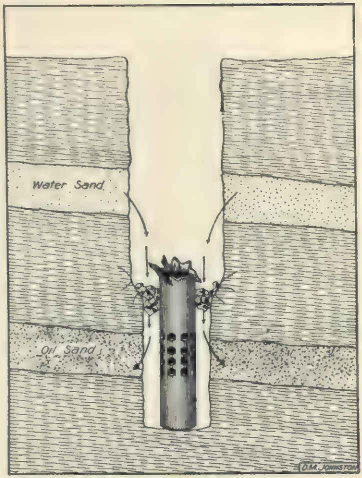


FIG. 8.—Sketch showing entrance of water into oil sand due to withdrawal of casing from an abandoned well without placing a plug between oil and water sands.

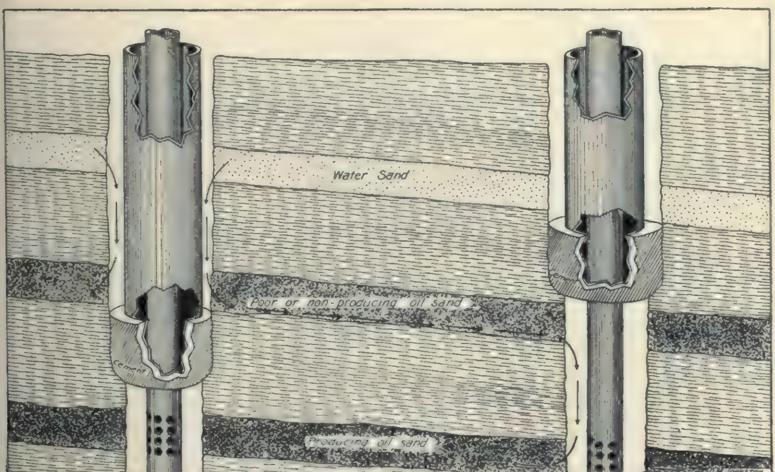


FIG. 9.—Sketch showing entrance of water due to lack of uniformity of distance of shut-off below water sands, when two wells penetrate the same strata. If there were only one well, either one would probably be in good condition.

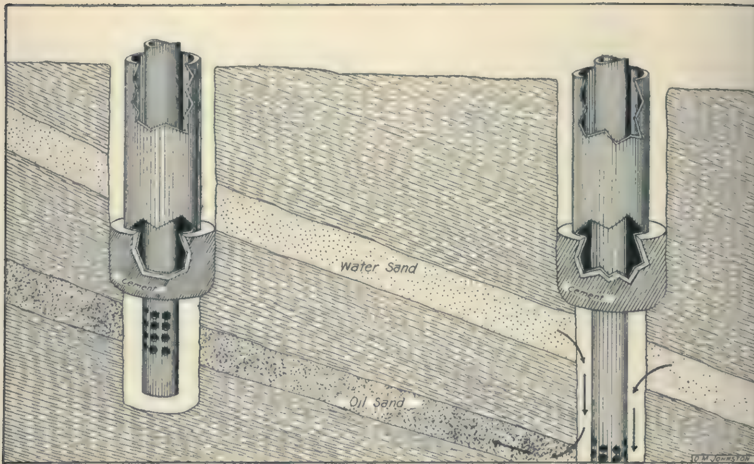


FIG. 10.—Sketch showing entrance of water due to fact that shut-off was made at the same depth in two wells, without considering the geological fact that strata most frequently do not lie parallel to the ground surface.

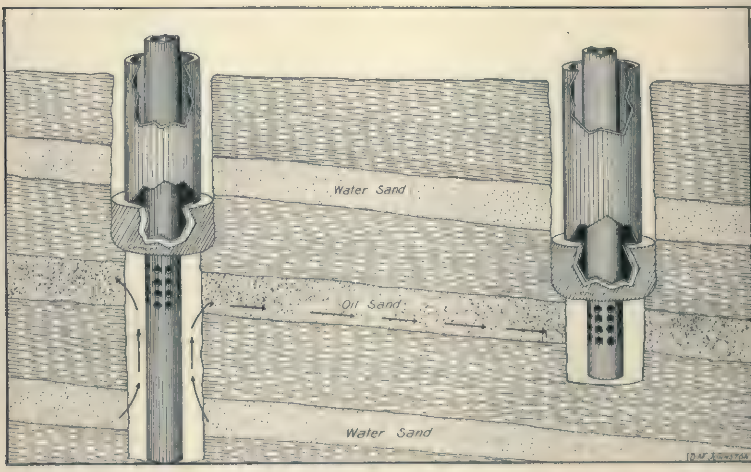


FIG. 11.—Sketch showing entrance of water into a properly drilled well, due to fact that another well drilled into a water bearing sand below the oil sand but did not plug the lower portion of the well.

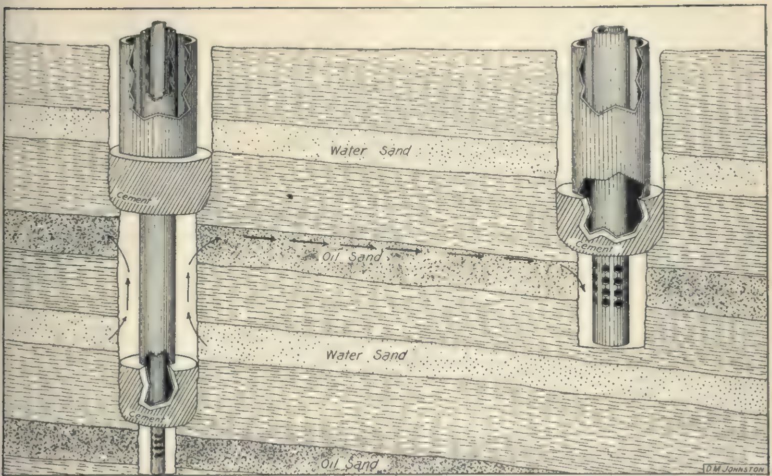


FIG. 12.—Sketch showing entrance of water into a properly drilled well because a neighboring well entered a deeper oil sand without inserting an extra string of casing to protect the first sand.

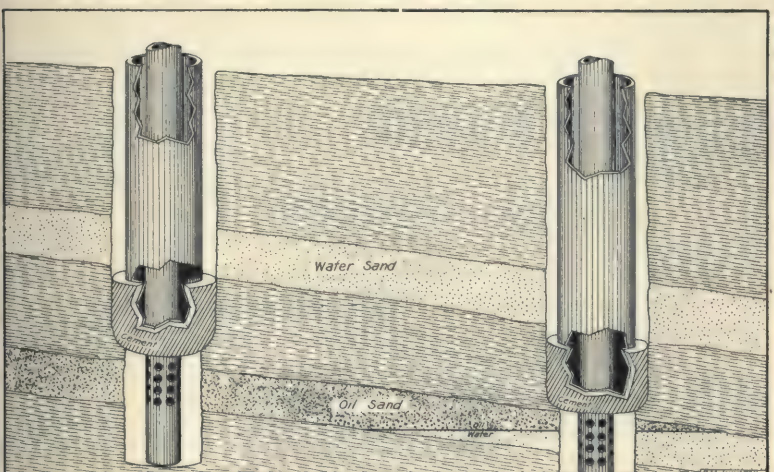


FIG. 13.—Sketch showing presence of edge water in one well due to a natural condition. Most oil sands when followed far enough down the dip, are found to contain only water. As oil is removed from above, water follows it up along the stratum.

It will be seen, from the foregoing sketches, that the number of separate strings of casing to be used in a well will depend upon the number of strata which are to be kept separated. The casing program is in fact one of the first things which must be definitely decided upon before drilling begins.

Log of Well.—In order that some knowledge may be gained as to geological conditions near a well, it is necessary, so far as possible, to identify and record the thickness, composition and content of the various strata which the drill penetrates. This is sometimes a simple matter owing to great differences in the nature of the strata. In other cases all the strata penetrated are so similar that it is difficult, if not impossible, to distinguish between them during the process of drilling. Identification of the various strata usually must be made from the comparatively small samples of drill cuttings which are brought to the surface. The action of the drilling tools, in the hands of an experienced and competent driller, frequently will indicate the nature of the rock encountered.

After a well is completed little or no evidence as to underground conditions will be available, except that which has been recorded from observation while drilling was in progress. Therefore, in order to obtain the necessary evidence in the form of a correct and complete record or log of a well, it is absolutely necessary that the drillers shall be thoroughly informed as to the nature and value of the information which is to be collected. The collection of this evidence involves the installation of a system which will provide for the collection of samples of drill cuttings and for the regular recording of all pertinent information.

Daily Drilling Reports.—The complete operations of the drilling crew should be written at the well every day. In fact the daily record should be so divided as to provide for recording the operations of each crew or shift of men.

One of the best methods for keeping daily drilling reports is to provide the necessary blanks in book form, with a page for each shift or tour. A carbon copy of each page should be made, which should be promptly removed from the book and filed in a safe

place, because the original book easily becomes soiled and illegible or may be lost. The daily drilling report should show the depth of the well at the beginning and at the end of the tour; also what sort of work the crew was engaged in, the size, weight and amount of casing put in or taken out. It should also show the depths at which changes of formation occurred, describe or name the formations, and state any evidence indicating the presence of oil, gas or water in the well.

The form of the daily drilling report can, of course, be designed to fit local conditions. The following form serves as an example which, with some alterations, can be adapted to most drilling operations.

No........ Well No.......Sec......

T......R.........

.... COMPANY

DRILLER'S TOUR REPORT

On Tour at 12 Midnight ....192...

CASING	
Size.....Weight.....Brand.....Shoe.....	Depth at Beginning of Tour.............ft.
Amount Put In......................ft.	Drilled During Tour..................ft.
Present Amount In...................ft.	Depth at End of Tour.................ft.

Lost Time..........Hours. Cause:...

REMARKS:..

....

....

....

Name of Tooldresser. (signed) Driller.

On Tour at 8 a. m.

CASING	
Size.....Weight.....Brand.....Shoe.....	Depth at Beginning of Tour.............ft.
Amount Put In......................ft.	Drilled During Tour..................ft.
Present Amount In...................ft.	Depth at End of Tour.................ft.

Lost Time..........Hours. Cause:...

REMARKS:..

....

....

....

Name of Tooldresser. (signed) Driller.

On Tour at 4 p. m.

CASING	Depth at Beginning of Tour.............ft.
Size.....Weight.....Brand.....Shoe.....	Drilled During Tour...................ft.
Amount Put In.........................	Depth at End of Tour..................ft.
Present Amount In...................ft.	

Lost Time..........Hours. Cause:..........................

REMARKS:..

....

....

....

Name of Tooldresser. (signed) Driller.

FORMATIONS

From.............ft. to...............ft.
From.............ft. to...............ft.
From.............ft. to...............ft.
From.............ft. to...............ft.
From.............ft. to...............ft.
From.............ft. to...............ft.
From.............ft. to...............ft.

Note all characteristics of Formations. Also Oil, Gas, Water, etc.

Measurement of Wells.—Under extremely favorable and simple underground conditions, it is sometimes only necessary to obtain approximate measurements of depths in oil wells. However, many very expensive errors have been caused by incorrect measurements. A difference of only one or two feet may directly affect the success or entire failure of the operator in drilling a well, as, for instance, failure to land casing in a thin bed of shale at which it is necessary to shut off water. Therefore, the prudent operator will always obtain accurate measurements, since they involve but little expense and loss of time.

The most obvious method of measuring the depth to the bottom of a well is to use a steel or aluminum tape with a weight attached at its lower end. Tape lines and reels are specially made for use in oil wells. The reel may be attached to the fly wheel of the drilling engine, or operated by hand.

The use of such tapes is common in some fields, particularly where drilling is done with Manila rope, which stretches to such an extent as to be unsuitable for accurate measurements. Measurements by tape and attached weight are suitable where only the depth to the bottom is desired. It is frequently necessary

to ascertain the depth to other points in a well, such as the lower end of a string of casing. The existence of many special conditions along the wall or casing of a well cannot be readily detected by a weighted line. The magnetic attraction between steel tape and well casing interferes to prevent accurate measurement.

The widespread use of steel cables for drilling and bailing wells has led to the practice of using them for measuring, with the result that in some fields the special measuring tape is never seen. When measurements are made directly with the drilling or bailing cable, many successive measurements can be made without much trouble, and a more detailed and accurate record is therefore apt to be kept. Care and attention must be given to the details if correct measurements are to be obtained with steel cable.

The following rules have been found sufficient to obtain results which are correct to within one foot.

1. All measurements should be made with steel tapes. Cloth or so-called "metallic" tapes can not be depended upon, as they are subject to great change in length by stretching. Measurements made with a five-foot stick upon a sand line or drilling line for distances of more than 200 ft. are inaccurate. The reason for such inaccuracy is that it is difficult to make markings at an exact point on the line at the ends of the stick, and the great number of inaccurately placed marks quickly multiplies the error.

2. The depth of the well should, in all cases, be determined by running a bailer or string of tools to the bottom. The unit of measurement, when cable tools are used, should be the distance from the floor of the derrick along the sand line to a fixed point near the reel. This unit of measurement is commonly known as the distance the derrick "measures over," and details for such measurement are stated below. When the measurement of a well is made on the drilling line, it should be made from the floor to a point near the bull-wheel shaft, five feet above the floor, as determined by setting up a five-foot stick.

The depth of a rotary hole, before casing is put in, should be

determined by measuring each stand of drill pipe with a steel tape, measurement to be made from the top of the tool-joint box to the bottom of the shoulder on the tool-joint pin.

3. The length of a string of casing should be determined by measuring to the shoe of the casing from the derrick floor. This measurement can be made on the drilling line by using an under-reamer, a latch-jack, or any other tool which definitely locates the shoe of the casing.

4. A derrick should be "measured over" immediately before measuring the depth of well or of casing. A measurement made when the rig is new may not be correct after the rig and rig-irons have been in use for some time.

The "distance over" can be determined in the following manner, using a bailer and sand-line:

(*a*) Run the bailer into the well a short distance and tie a string (target) on the sand-line level with the surface of the floor, using a steel square or other straight edge to determine the correct position.

(*b*) Tie a second string or strand of rope tightly on the sand-line at a fixed point near the sand-line reel.

(*c*) Lower the bailer into the well until the second target is within easy reach from the derrick floor. Attach the end of a steel tape to the sand-line at the target. Raise the bailer so that another target may be fastened to the line at the end of the tape. Lower the bailer, detach the tape; hoist the bailer and attach the tape at the third target; hoist the bailer and set a fourth target. Repeat the operation until the tape reaches the first target originaly set at the level of the floor. The tape must be shorter than the height of the derrick, so that it will not go over the pulley at the crown block.

When a target is tied to the drilling or sand-line, paint should be applied to it above and below the target, to show any displacement of the target.

To measure into the well, after the unit length or "distance over" is determined, hold the bottom of the bailer-dart, when raised, level with the surface of the floor, set a target at a fixed

point near the reel, lower the bailer until the target is level with the floor, and set a second target at the reel. Correct count of the targets is most easily kept by detaching and keeping each one as it reaches the floor.

The depth can be less conveniently measured when the bailer is pulled out of the well by setting the first target even with the floor, while the bailer is on bottom, hoisting until the target reaches the reel, set new targets at floor level and remove old ones as they reach the reel.

Measurements of depth are frequently determined from the amount of casing put into a well. This method is not accurate under ordinary conditions. The total length of a string of casing can not be correctly determined by adding together the lengths of separate joints because it is impossible to know exactly how far each joint will screw into the collars. Measurements of separate joints, after each one is screwed into place and before it is lowered into the well, will not give an accurate total, because the entire string may be still more tightly screwed together. Strings of casing 2000 ft. long have sometimes been shortened as much as two feet by additional screwing together after being placed in the well.

Special measurements, such as that to the casing shoe, are sometimes satisfactorily made with the pump tubing. The tubing is accurately measured as it is put into the well, and a hook is fastened to it near its bottom. The hook is caught on the casing shoe by lifting or lowering and turning the tubing, and after the measurement is ascertained, the tubing may be withdrawn whenever convenient.[1]

Identification of Strata.—It is necessary to identify the strata penetrated by a well in order to know where drilling should stop and where casing should be landed and perforated.

The identification must be made by some system which affords comparison with other records of known geological conditions in

[1]Measuring Casing. M. H. Soyster and John H. Dougherty. Fifth Annual Report of State Oil and Gas Supervisor of California. Vol. 5, No. 5, pp. 5–10.

the vicinity. The comparison may be made either with evidence furnished by logs of neighboring wells or with a record of strata where they are exposed at the ground surface. In either method the most obvious characteristics, such as color, texture and hardness of the rock, will be most useful in preliminary records or logs.

Samples of drill cuttings vary with the kind of tools used. Cable tools ordinarily yield better samples than rotary tools, but the physical conditions governing the collection of either kind of samples are not ideal and their effect must therefore be considered.

With cable tools the bailer can be used to collect the drill cuttings at almost any place in the well. However, the action of the drill will usually pulverize the rock to such an extent that its appearance may be greatly changed, and, furthermore, the sample will usually be mixed with water and the finer particles are easily lost. A positive identification requires that the entire contents of the bailer be saved so that the mud or slime can be examined as well as the larger fragments of rock. In some localities the upper formations will continually contribute to the adulteration of the cuttings collected at the bottom of the well. There may be cases where casing will have to be landed in order that clean and representative samples may be obtained.

Where rotary tools are used the samples are usually obtained as the drill cuttings appear at the surface with the drilling water which rises alongside the tools. After the drill enters a stratum some time will elapse, varying from 15 to 40 minutes or even longer, before the cuttings will appear at the surface. The sample will therefore be thoroughly mixed and washed. A skilled driller can frequently recognize a change in underground formation by the behavior of the tools. When a change in formation is noted by the driller, it is sometimes advisable merely to rotate the drill, without gaining depth, until cuttings of the new formation appear at the surface.

The time required for rotary cuttings to reach the surface will vary with the size and depth of the hole and the volume of water

furnished by the pump. An approximate determination of the time can be made by a test which consists of adding some distinctive coloring matter, such as brick dust, to the drilling water, and noting the time elapsed before its reappearance, due consideration being taken of the pump speed and the inside diameter of the drill stem.

When the rotary-bit is withdrawn from the well a sample of formation will sometimes be found upon it. However, such an occurrence is exceptional, and as considerable time is required to withdraw and replace the bit, little practicable dependence can be placed upon such a method.

Sampling devices are sometimes attached to rotary tools for the purpose of gathering a sample at the bottom of the hole. This procedure can be adopted for special samples of particular importance, but it has not yet been developed or perfected so as to gather samples economically of all formations penetrated. A distinct field of usefulness for new and Improved sampling devices exists.

Experimental drilling with core drills indicates that the process may be developed to usefulness.

Where either rotary or cable tools are used, it is advisable to save small samples of cuttings and place them in separate bottles or boxes which must be accurately labeled. A complete collection of such samples may be readily examined and compared with others so that identification is more likely to be correct.

If considerable drilling work is being carried on, one man should be detailed to visit regularly the various wells for the purpose of collecting the samples and classifying them. Such a classification by one man will tend to uniformity in the names which will be applied. If the person who collects the samples has had experience and training in geological work, the value of the classification of samples would be enhanced. If each driller merely notes his individual observations, using various names for formations, the records will vary so widely that geological comparison may be difficult or impossible.

Recent work by J. A. Udden and other scientists has proved

that microscopic examination of drill cuttings is economically useful in many cases.

After several wells have been drilled and the logs carefully compared, some striking and unmistakable strata usually develop which may thereafter be carefully watched for as markers, and the remainder of the log may be given only incidental attention.

Water Encountered during Drilling.—The characteristics of water encountered during the process of drilling an oil well should be carefully noted. An important reason for such care is that the water must be excluded from the oil bearing formations in order to secure the maximum production and profit. Furthermore, the water originally found in certain strata is frequently different from that found in overlying or underlying strata and therefore helps to identify the strata.

Some of the more important characteristics of water to be noted are volume, head, purity and temperature.

The volume of water encountered will usually be measured by bailing, when cable tools are used. Sometimes the water will flow out of the top of the well in which case it is possible to measure it by tank, meter or weir, regardless of the kind of drilling tools in use.

The head of water, or the level to which it will rise if undisturbed, is an important fact to be determined because it affects the volume or flow in some cases, and, furthermore, it sometimes indicates the source of the water. It must be remembered that the level to which water will rise in a well may vary if neighborhood conditions are changed so as to either raise or lower the general fluid level. The accompanying sketch (Fig. 14) by M. J. Kirwan[1] shows such a change in fluid level at a group of wells. The level shown by line "B" prevailed about a year after that shown by line "A." The highest point in the more recent line was caused by the condition of a single well into which water found entrance, which raised the fluid in some of the nearby wells.

The fact that in this particular instance the comparison of

[1] California State Mining Bureau *Bulletin* 82. 1918. Second Annual Report of State Oil and Gas Supervisor, p. 30.

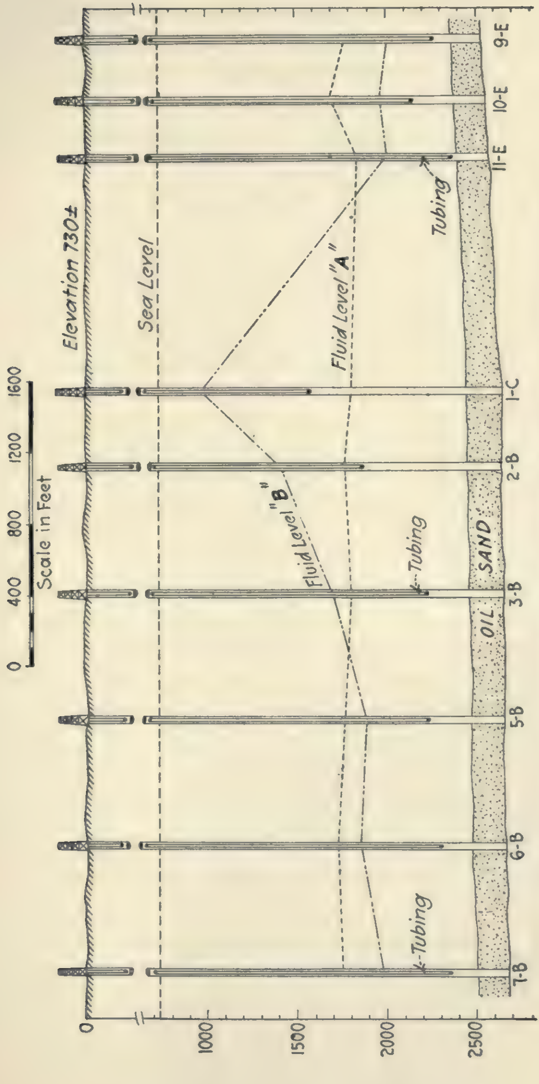


FIG. 14.—Cross-section showing change of fluid level in several oil wells.

fluid levels assisted in determining the source of damage to the entire group of wells emphasizes the value of determining the head of water not only when it is first encountered, but also at subsequent dates.

The purity of water, or rather the degree of its impurity, is frequently a definite clue to its underground source. In one locality, for instance,[1] the water lying below a certain oil zone carries about twice the amount of dissolved mineral salts as does the upper or overlying water. Chlorides and carbonates predominate in the lower water, while sulphates predominate in the upper water. It should not be understood that definite proportions are to be expected in all localities. However, careful comparison of water samples in any field will frequently develop some rule for that locality.

Determination of the purity of water does not always require a chemical analysis. Taste and odor will frequently serve to differentiate between two samples of water. A correct and complete log of a well should always mention such simple characteristics.

After a well is completed, or after several water bearing strata have been penetrated, it may be difficult or impossible to obtain separate samples from each stratum; therefore, the observations should be made while drilling is in progress.

Complete and accurate analyses of water encountered in drilling will undoubtedly lead to the discovery of conditions having economic importance, and should be made, wherever practicable.[2]

Simple tests yielding incomplete information as to the chemical content of water have been found useful, because they can be made quickly and require very little apparatus. They may be devised to determine the percentage of chlorides, carbonates

[1] *Bulletin* 73, California State Mining Bureau, p. 86.

[2] Rogers, G. S., Chemical Relations of the Oil Field Waters in San Joaquin Valley, California. U. S. Geol. Survey, *Bulletin* 653, 1917; Geochemi al Relations of Oil, Gas and Water, Sunset Midway Oil Field, California. U. S. Geol. Survey, *Professional Paper* 117, Part II.

Palmer, Chase, The Geochemical Interpretation of Water Analyses, U. S. Geol. Survey, *Bulletin* 479, 1911.

or sulphates. After slight practice and instruction these tests can be made by persons having little or no technical knowledge of chemistry.

Short-cut methods of water analyses may not receive the approval of some analysts, but they are unquestionably justified for the purpose here mentioned. Investigation of quick methods of water analysis was made by M. O. Leighton,[1] and his introductory remarks are worthy of quotation.

"A chemist aims to secure exceeding refinement in analytical methods and results. He seldom considers whether or not a method is sufficiently exact for certain broad purposes. The fact that it is incomplete, approximate, or susceptible of refinement is to him sufficient reason for improving or rejecting it at the first opportunity.

"The scrutiny to which chemical methods have been subjected in the endeavor to secure exact results has led in many cases to processes so complicated and expensive that in commercial work the advantages do not compensate for the increased cost and delay which the methods involve. The result has been that the chemical profession distinguishes between two classes of chemical methods which differ in degree of accuracy. The first includes the exact methods, which afford results as nearly perfect as chemical procedure will permit. Such methods are used in all cases where minute differences in analysis would cause errors in interpretation or in subsequent chemical procedure. The second class ocnsists of "commercial methods," so-called because the results obtained by them, while departing from the actual truth, are sufficiently accurate to insure the profitable conduct of industrial chemical processes without appreciable error or waste. Methods of the first class are the product of chemistry while those of the second are used in response to the demands of expediency—they are good enough for the purposes for which they are used.

"In no branch of chemistry are approximate results more serviceable than in the analysis of water for hydro-economic surveys, or surveys made to determine the value of water and its applicability for use in domestic supply, boilers, industries, etc. Under the conditions which generally prevail it is necessary to resort to long, tedious and expensive processes in order to secure a determination of the character and amount

[1] Field Assay of Water. M. O. LEIGHTON, *Water Supply and Irrigation Paper* No. 151. U. S. Geol. Survey, 1905.

of foreign constituents in water. It is the practice in such cases to secure a sample of the water and transport it to a laboratory, where, after conventional delays, it is passed through the usual course of analysis.

"There has been surprisingly little discrimination used in the past with reference to the selection of determinations for specific purposes, and as a general rule the same procedure has usually been followed without regard to the object of the particular investigation. If the purpose of the analysis is to determine the incrusting constituents, the course pursued has been to follow the entire analytical procedure. If, on the other hand, it is desired to determine the amount of organic pollution in a water and show its value for domestic use, the chemist forthwith begins the round of nitrogen determinations, and closes with a statement of the oxygen consumed and the number of bacteria per cubic centimeter. In only a few well-known laboratories has this rule been violated, and such is the conservatism in the chemical profession that it will probably be followed largely in future. Conservatism is the safeguard of science and one of the most commendable qualities of a chemist, but an excess is sometimes almost as bad as a deficiency."

It is unnecessary to outline here methods of water analysis as the subject has been well covered in many publications,[1] but the details of testing for chloride will illustrate the comparative simplicity of the work and encourage a more general use of chemical analyses.[2] The solutions can be standardized at a laboratory and furnished to the field observer who can quickly make the necessary tests.

Solutions Required in the Analysis of Water for Chlorine

"The following solutions are employed in the analysis of water for chlorine:

"**Salt Solution.**—A solution of chemically pure fused salt, containing 1 milligram of chlorine in each cubic centimeter, is made by dissolving 1.648 grams of the fused sodium chloride in 1 liter of distilled water free from chlorine.

[1] R. B. Dole, The Quality of Surface Waters in the United States, *Water Supply Paper* 236, Part I, U. S. Geol. Survey, pp. 9–27, 1909.

[2] *Water Supply and Irrigation Paper* No. 151, U. S. Geol. Survey, pp. 49–50.

"**Silver-nitrate Solution.**—Two and one-half grams of crystallized silver nitrate are dissolved in 1 liter of distilled water free from chlorine. To this solution water or strong silver-nitrate is added until by actual titration 10 cubic centimeters of it are equal to 5 cubic centimeters of the standard salt solution. One cubic centimeter of this solution is then equal to 0.5 milligram of chlorine.

"**Potassium-chromate Solution.**—An indicator solution is made by adding 50 grams of potassium chromate to 1 liter of distilled water and then adding sufficient silver-nitrate solution to precipitate all the chlorine present and turn the precipitate slightly reddish. This is allowed to stand, and by filtering or decanting the clear solution is then obtained.

"**Emulsion of Alumina.**—This is made by dissolving 125 grams of potassium or ammonium alum in 1 liter of water and precipitating the alumina from boiling solution by ammonia. After precipitation the alumina must be washed free from chloriné sulphate and ammonia by successive treatments, settlings, and decantations with cold distilled water.

Method of Procedure in the Analysis of Water for Chlorine

"Pour 25 cubic centimeters of the water to be tested into a white porcelain dish. Add about one-half a cubic centimeter of chromate solution and run in standard silver-nitrate solution from a burette until the first faint reddish tint appears. This is more easily noted if for comparison a dish containing the same amount of water and chromate is kept beside the dish in which the test is made.

"If one or more cubic centimeters of silver-nitrate are necessary to reach an end point, the test may be made without evaporation, but if less is required then evaporate 250 cubic centimeters to 25 cubic centimeters volume before making the test. It may at times be necessary to evaporate more than this if the chlorine present is very close to zero in amount.

"It is best always to titrate with 25 cubic centimeters of the water. In this case 0.1 cubic centimeter is subtracted from the results as an indicator error. If more than this amount is used in titration, subtract 0.1 cubic centimeter for each 25 cubic centimeters of the volume of water titrated.

"If 250 cubic centimeters of water are taken, the number of cubic centimeters of silver-nitrate solution used to obtain an end point minus

0.1 cubic centimeter multipled by 2, gives the chlorine in parts per million.

"**Example:** 250 cubic centimeters are evaporated to a volume of 25 cubic centimeters and chromate solution added. In the titration 3.5 cubic centimeters of silver-nitrate are used. Then $(3.5 - 0.1) \times 2 = 6.8$. The water, then, contains 6.8 parts per million of chlorine."

The temperature of waters encountered in drilling oil wells varies so widely that differences are sometimes observed and recorded without an effort to measure the exact temperature. In many cases, it will be found advisable to determine accurately the temperature of water, as well as of oil, for the purpose of identifying its source.

Where several water bearing strata contribute to the supply of water in a well there may be difficulty in determining the temperature from each stratum. The most favorable conditions for such determination will probably exist while the well is drilling, and where it may be possible to exclude, at least temporarily, certain flows.

Oil Encountered during Drilling.—It might seem superfluous to say that the occurrence of oil should always be recorded in the log of a well, in view of the fact that its discovery is the prime reason for drilling. Many wells, however, have failed to yield profitable production on account of carelessness in observing and recording oil which was actually encountered. Many experienced oil operators claim they can distinguish a difference between samples of sand which carry oil or water. Such a claim is untenable. There is no inherent difference between sands which carry oil and those which carry water.

The only certain method of determining that rock is oil-bearing is actually to find oil in it. Sometimes the oil can be seen readily or its presence may be detected by the odor. Washing an oil sand in water will frequently liberate the oil, which can then be seen floating on the water.

Some kinds of oil will discolor chloroform or ether, giving the liquid a brown color. The presence of such oils in rock can be detected by dropping finely crushed fragments of the impreg-

nated rock into a glass test tube containing chloroform or ether. Water in the rock may interfere with this test, but that obstacle can be avoided by first soaking the rock in alcohol which will absorb the water. Sometimes a sample may be carefully dried so that the presence of oil may be detected by the chloroform or ether test. If too much heat is applied in drying the sample, however, there is risk of driving off all the oil.

Tests of rock, by ether or chloroform, which disclose the presence of oil do not prove that it is present in commercial quantities. However, this test is widely used, and the prudent operator will always make use of it where there may be danger of over-looking productive formations.

Water standing in a well will frequently prevent oil from entering, even though oil bearing formations have been penetrated and are actually standing exposed in the well. In some localities, such as most of the California fields, the possibility of a stratum producing oil cannot be definitely determined until water is entirely excluded from the well and a bailing or pumping test conducted. These precautionary tests doubtless will prove useful in many localities where they have not been used.

Hard or compact formations frequently retain oil until after the well has been shot, and in some cases the wells must be swabbed in order to start a profitable flow of oil.

Where rotary tools are used in drilling a well the presence of oil will be indicated on the surface of the water or mud which returns from the bottom of the well outside the drill stem. Heavy mud may obscure a very good showing of oil so that the oil bearing formation may be passed through without recognition. Many wells have passed through oil sands without their being noted, and their true nature has subsequently been disclosed during repair or redrilling work. Some wells have finally flowed oil at the rate of several thousand barrels per day although the original drilling developed an apparently "dry hole." The utmost vigilance therefore is necessary when rotary tools are used. Upon the appearance of the slightest showing of oil the downward progress of the tools should be stopped and the cir-

culating mud made as thin as possible. Furthermore, clean water and mud should be introduced into the tools. Even with these precautions it may, in doubtful cases, be necessary to withdraw the tools, set a string of casing and test the well by bailing. This last step is, of course, an extreme measure because in some formations the casing can not be again removed, and the diameter of the hole is permanently reduced so that further drilling may be difficult if not impossible.

Under such adverse conditions as have just been cited, it is absolutely necessary to have a definite knowledge of underground conditions as shown by correct logs of neighboring wells.

Gas Encountered in Drilling.—Gas, like water and oil, is frequently a characteristic of certain strata and should be carefully noted during drilling so that the stratigraphic relations between wells may be accurately compared or correlated. Furthermore, the development of gas itself will frequently be profitable.

Gas usually manifests its presence, where cable tools are used, either by blowing the water out of the hole or rising through the water in unmistakable manner. A low pressure of gas sometimes makes its presence manifest only when the well is bailed nearly dry.

Every evidence of the presence of gas should be fully recorded in the daily drilling reports.

With rotary tools the presence of gas is manifested by bubbles in the circulating mud as it comes from the well. However, it is readily obscured by heavy mud, and may be passed through without recognition. All the precautions taken to observe traces of oil must also be applied if gas is to be discovered. Well authenticated instances are known where gas under considerable pressure has been drilled through without recognition, notably in the case of the Elk Hills field of California[1] with a pressure of more than 400 lbs. per square inch, and a volume exceeding thirty million cubic feet per day.

[1] Fourth Annual Report, State Oil and Gas Supervisor of California. May, 1919, pp. 4–8.

Permanent Record of Drilling.—When all the necessary care above outlined has been taken, and the advised precautions observed, the well-owner will possess a fairly complete record or inventory of the condition of his property.

The daily drilling reports, when filed in regular order, will serve as a guide to intelligent repair or maintenance of the well and will also furnish information as to how neighboring wells can be properly and most economically drilled. The daily reports will be voluminous, and should therefore be condensed for the purpose of ready reference and easy comprehension. This end can be best achieved by keeping a summarized record-book in conjunction with the daily reports.

In addition to this record-book, a complete log should be written, with duplicate copies sufficient in number to supply each individual or department concerned. The written log should be revised whenever any additional work is performed at the well.

The details of a form for a written log may of necessity vary slightly with local conditions. The following form has been found adequate for some ten thousand wells and may therefore serve as a suggestion for others:

For convenience of filing, all the forms should be on letter size paper (11 × 8½ inches), with the exception of Form 1, which may be double length, and by folding will serve as a cover or container for the others. The paper should be thin enough to permit making several carbon copies.

Exclusion of Water from Oil Wells.—The damage caused by the entrance of water into oil wells is so well recognized that it is deemed unnecessary to dwell upon that feature to the extent of citing examples. However, it appears that many experienced oil operators do not yet realize that the damage can be avoided, or even remedied; therefore consideration of precautionary and remedial measures is clearly worth while.

Damage to oil fields by water arises from the fact that when water enters a porous stratum saturated with oil, it tends to displace the oil. If the entrance of water is at or near an oil well it frequently dries the oil away from the well, which then

Fill this blank in with typewriter Write on one side of paper only

LOG OF OIL OR GAS WELL

FIELD.. COMPANY ....

Township..............Range..............Section.............Elevation..................Number of Well.........

The information given herewith is a complete and correct record of the present condition of the well and all work done thereon, so far as can be determined from all available records.

Signed..

Date.. Title..

The summary on this page is for the ORIGINAL condition of the well

OIL SANDS

1st sand from....................to.................... 4th sand from....................to....................
2d sand from....................to.................... 5th sand from....................to....................
3d sand from....................to.................... 6th sand from....................to....................

IMPORTANT WATER SANDS

1st sand from....................to.................... 3d sand from....................to....................
2d sand from....................to.................... 4th sand from....................to....................

CASING RECORD

Size of Casing	Where Landed	Where Cut	Weight Per Foot	Threads Per Inch	Kind of Shoe	Make of Casing	Cemented Yes	No	Number of Sacks

CEMENTING OR OTHER SHUT-OFF RECORD

Casing, Size	Sacks	Time Set	Method	Test and Result (Give water level and bailing results)

PLUGS AND ADAPTERS

Heaving Plug—Material....................................Length....................Where set..........

Adapters —Material....................................Size....................................

TOOLS

Rotary Tools were used from....................................ft. to....................ft....................

Cable Tools were used from....................................ft. to....................ft....................

PERFORATIONS

State clearly whether a machine was used or casing was drilled in shop

From	To	Size of Holes	Number of Rows	Holes Per Foot	Machine—Shop
ft.	ft.				
ft.	ft.				
ft.	ft.				
ft.	ft.				
ft.	ft.				

Thirty days after completion well produced..............barrels of oil per day.

The gravity of oil was..............degrees Baumé. Water in oil amounted to..............per cent.

NAMES OF DRILLERS	NAMES OF TOOL DRESSERS
....	....
....	....
....	....

Date drilling started .... Date well was completed....................................

FORMATIONS PENETRATED BY WELL

Depth to Top of Formation	Depth to Bottom of Formation	Thickness	Name of Formation

FORM 1

FIELD ________________ COMPANY ________________

Township ________ *Range* ________ *Section* ________ *Number of well* ________

FORMATIONS PENETRATED BY WELL

Depth to		Thickness	Name of Formation
Top of Formation	Bottom of Formation		

FORM 2

HISTORY OF OIL OR GAS WELL

FIELD ________________ COMPANY ________________

Township ________ *Range* ________ *Section* ________ *Number of well* ________

Signed ________________

Date ________________ Title ________________

It is of the greatest importance to have a complete history of the well. Please state in detail the dates of redrilling, together with the reasons for the work and its results. If there were any changes made in the casing, state fully, and if any casing was "sidetracked" or left in the well give its size and location. If the well has been dynamited give date, size, position, and number of shots. If plugs or bridges were put in to test for water state kind of material used, position, and results of pumping or bailing.

FORM 3

LOG OF OIL OR GAS WELL

FIELD ________________ COMPANY ________________

Township ________ *Range* ________ *Section* ________ *Number of well* ________

The information given herewith is a complete and correct record of all work done on the well since the previous record, dated ________________, was filed.

Signed ________________

Date ________________ Title ________________

FORM 4

produces only water. When this condition continues along the strata, neighboring wells are affected in a like manner.

The entrance of water into an oil-bearing stratum in the drilling of wells is due to two primary causes; first, incomplete knowledge of geological conditions surrounding the well; and second, faulty mechanical conditions existing in its drilling or maintenance. Many combinations of these two causes exist, and a general idea of them can most easily be gained by the examination and consideration of the sketches shown in Figs. 4 to 13. These sketches merely illustrate a few typical cases, and do not cover all the various complications due to geological and mechanical conditions.

Damaging water conditions are frequently accounted for by the statement that all the oil has been exhausted from a stratum, and therefore water naturally replaces it. Another frequent explanation is that the oil and water have both collected naturally in the same underground reservoir, and therefore the production of clean oil is impossible. Neither of these explanations should be accepted until a careful and exhaustive examination has eliminated all other possible explanations.

Definitions of the various terms used herein in the control of water in oil wells can be most readily understood by reference to the sketches mentioned above.

Formation Shut-off.—The landing of casing in the walls of the well in such a manner as to prevent the passage of water without use of cement, as illustrated in Fig. 4.

Water String.—The casing placed in the well primarily for the purpose of preventing water from flowing from its original position to other strata below the shoe of the water string, as illustrated by the casing of larger diameter in Fig. 5.

"*Top Water.*"—The water found in strata lying above the productive oil formation penetrated by a certain well, as illustrated in Figs. 4 to 10, inclusive. The term is indefinite and should be avoided by using a statement specifically mentioning the depth at which the water occurs.

"*Bottom Water,*"—The water found in strata lying below the

productive oil formation penetrated by a certain well, as illustrated in Fig. 11. The term is indefinite and should be avoided as mentioned in the foregoing paragraph.

Intermediate Water.—The water found in strata between productive oil formations penetrated by a certain well, as illustrated in Fig. 12.

Edge Water.—The water found in a sand which contains oil at a higher elevation or, in other words, farther up the dip. Illustrated in Fig. 13.

Water can in most cases be excluded from an oil well while it is being drilled, if sufficient care and attention are given to the matter. The old adage, "an ounce of prevention is worth a pound of cure," is particularly applicable to this problem. The foregoing pages have outlined methods for gathering pertinent facts, and the next chapter shows how they can be assembled in useful and intelligible form. The mechanical methods involved in actually excluding water from a well must always be governed by the existing underground conditions many of which can only be surmised from the facts observed.

Methods of Excluding Water.—In most oil fields some water is found in the formations overlying the oil sands. There are a number of methods in use for excluding this water from the wells, and of course local conditions must be taken into account in the choice of the method used in any particular case. Water in shallow wells is often successfully handled by landing the casing in impervious strata, but in deep drilling in California hydraulic cement is used, in the majority of cases.

Formation shut-off is the term applied to a shut-off where casing is landed in a bed of shale or clay without using cement or other device to plug the space between the casing and the wall of the hole. In this operation much depends upon the kind of casing-shoe which is used. It should be a plain shoe, as distinguished from the notched Baker shoe and from the types used in rotary drilling. A shoe 14 to 20 in. in length is usually used, although in a few cases in deep work shoes from 6 to 20 ft. in length have been successfully used. It is important not to have

the largest diameter of the shoe at the bottom in order that it can be driven tightly into the formation. When a suitable shale or clay is reached where it is desired to land the water string, the hole is drilled ahead with a smaller-sized bit and the casing is driven until the shoe is tight in the formation. This will prevent the water from following down the outside of the casing and entering the well below.

The first attempted substitute for the formation shut-off, consisted of clay and chopped rope which were put into the well to fill up and seal the space between the shoe and the wall. A now obsolete practice, which was in vogue before the use of cement, was to make a landing on a hard lens or "shell," as it is usually termed, and then depend upon a bag of flaxseed to seal the space around the shoe. The hole was carefully trued up, cuttings removed, the seed bag lowered into the hole and the casing landed on it. The swelling of the seed from the absorption of water was depended upon to hold it back long enough to allow the mud to settle and the formation to close in sufficiently to make a permanent job.

The method of tamping, which has been in use for a number of years, now has but few followers. By this method a complicated expanding packer was attached to the oil string where it was desired to make a shut-off, and located below the next larger string of pipe. The packer was made of canvas and closely resembled an inverted umbrella. Sand and pulverized shale was then introduced between the casings by means of a stream of water, and the outer string constantly moved up and down to facilitate the downward movement of the material introduced, as well as to tamp it tightly around the shoe. As the space filled up, the tamping string was removed joint by joint. This operation took from three to six weeks to accomplish. Advocates of this practice claim in justification that the casing recovered repaid the labor involved. By this method a string of casing is saved, the last string serving the double purpose of an oil and water string. It is readily seen that this process could only be applied where formations stand up sufficiently to allow the removal of casing at will.

Hydraulic cement is now being generally used in California for

excluding water from oil sands. The so-called "dump-bailer" method is the simplest in use. In this process the hole is first trued up and carefully cleared of cuttings if the shut-off is to be made at the bottom of the hole. If the hole has already been carried below the shut-off point it is necessary to put in a bridge or false bottom. The casing is then raised off the bottom and thirty or forty sacks of cement, mixed to the consistency of thin gruel, are lowered to the bottom by means of the dump-bailer. The casing is then filled with water to the top and a cap screwed on; then when the casing is lowered to the bottom, the cement is forced out behind it. Sufficient time is allowed for the cement to set, and if the displacements have been accurately figured, only a few feet will remain on the inside of the casing, which is easily drilled out. One of the advantages of this method is that the mud used in drilling can be left behind the casing. In experienced hands this method has achieved a large percentage of successful shut-offs, even in deep territory. The amount of cement that can be used is necessarily limited, consequently this method is applicable only to cases where no large cavities are to be filled, such as those which often occur in redrilling, or are occasioned by other troubles in wells.

The pumping of cement into the space between the wall and casing is now the method in most general use. For this purpose complete cementing outfits are mounted on auto-trucks, and steam connections are made with the boiler at the well. Two pumps are generally used. The work is usually started with a pump capable of delivering a pressure of 300 to 400 lbs. and finished with one capable of delivering 700 to 800 lbs. The cement is mixed in a portable mixing trough. Neat cement is used, and as in the use of the dump-bailer method it is mixed with water to the consistency of thin gruel. The details of this method vary considerably. In all cases it is important to true up the bottom of the hole and remove the cuttings. The casing is raised a few feet from the bottom while the cement is being pumped, and then lowered to its final position after the cement is in place. Some operators force water upward outside the casing,

prior to introducing the cement, until the clear water comes to the surface. Others leave as much circulating mud in the hole as possible, only pumping in sufficient clean water in advance of the cement to prevent the mud mixing with it, the idea being to allow this mud to settle around the casing and thus prevent the movement of water from one stratum to another.

An early method, now little used, was to pump cement through tubing, a packer being placed at the bottom of the casing to prevent the return of the cement between the tubing and the casing. An improvement on this method, now extensively used, is to pump the cement through tubing which passes through a casing-head fitted to the top of the water string and provided with a release valve. The tubing is lowered to within a few feet of the casing shoe, the exact distance being governed by the amount of cement it is desired to leave in the casing. Water is pumped in to obtain circulation outside the casing, then the casing-head release valve is opened and the casing is pumped full of water, which, when the release is closed, prevents the cement from coming up between the tubing and the casing, and forces it outside the casing. After the cement is in place, the casing is lowered and all connections closed until the cement has taken its initial set in order to prevent a possible return of the cement around the shoe. There are two methods of determining when the cement has been forced out from the tubing. The first is to calculate the capacity of the tubing and measure the required amount of water. The second is to reduce the diameter of the lower end of the tubing with a swedge nipple. After the cement has been applied, and before the displacing water has been pumped in, a wooden plug is inserted in the tubing. When the plug reaches the swedge nipple and the cement has been displaced the pump pressure suddenly rises and the circulation stops.

The majority of operators now pump the cement directly into the casing and then force it out behind the casing by filling it with water. Some operators figure the contents of the casing and stop the pumps when the calculated amount of water has been pumped in. In some cases the water is measured with a meter, while in

others it is measured in tanks, the latter method being considered less risky and more accurate.

Another method consists in using two wooden plugs about three feet long, which are made to fit tightly against the casing by means of rubber belting. These plugs are introduced into the casing by the use of a special arrangement of gates and fittings. The first plug is started down the casing ahead of the cement to prevent the water and cement mixing. The usual practice is to raise the casing about 18 in. so that the upper portion of the first plug remains in the casing. Sometimes a wooden "spreader," 2 in. by 4 in. and 6 ft. to 15 ft. long, is inserted ahead of the second plug. This "spreader" serves to retain within this casing cement which has become excessively diluted, and which would otherwise rest at the critical position immediately around the shoe of the casing. The plugs and "spreader" are afterwards easily drilled out. The second plug is introduced after the cement is pumped in and the casing lowered, so that the plugs and "spreader" will not pass out of the casing but come to rest, and thus increase the pressure of the pumps when all the cement has left the casing. In using this method it is customary to measure the water pumped in behind the second plug as a check on the progress of the operation.

The amount of cement used varies from 5 to 30 tons, according to local conditions. On an ordinary job, without any complications resulting from caving, 10 to 15 tons are used. Most operators use larger quantities than are needed for the simple purpose of plugging off water behind the shoes, because it serves to reinforce the casing by filling the space between the casing and the wall, and also prevents corrosion from waters carrying mineral salts. It is not uncommon to find in redrilling abandoned wells, where large amounts of cement had been used, that the cement has followed up the casing as much as 1000 ft. In localities where formations showed a decided tendency to cause the casing to collapse after the completion of wells, as much as 30 tons of cement have been used with the hope of holding back the walls and preventing this collapse.

The shutting off of "bottom water" is a different problem, and usually a much more difficult one to overcome than is presented in shutting off "top water." Oil sands have been drilled through where the operator has often had to contend with gas and loose sand, as well as sidetracked or slivered casing. To remedy these conditions the hole must first be cleaned out and, if any casing was left in the well when the oil string was pulled, it must be shattered with dynamite and plugged above the water sand. Some operators have succeeded in meeting these difficulties by inserting rope, brick, or similar materials, and tamping them down thoroughly with the tools. On top of such a foundation is placed a mixture of dry cement and metal lathe cuttings in tin cartridges and tamped down. These cartridges are then broken up and the cement mixed with water in the hole by the action of the tools. Other operators have been successful by simply placing enough neat cement in the well with a dump bailer to fill it up to the bottom of the lowest oil sands.

Probably the best method, and the one that has met with success under the most difficult conditions, consists in pumping the cement through tubing, which enables the operator to exert sufficient pressure to force it into cavities and channels that would not otherwise be filled. The outfit used is similar to that described above for cementing a water string with tubing and casing-head. The space between the oil and water string is closed at the top of the water string, thus preventing the cement from coming up between these two casings. The packing head closing the space between the two casings is so constructed as to allow the movement of the oil string through it, if that is desired. It frequently happens by the use of this method that the oil sands will absorb considerable water, and continue to do so until the cement comes up and shuts them off to some extent. Thus the pump pressure is increased and forces the cement into the formation below. The oil sands thereafter become somewhat deadened, and it may be some time before the former production is obtained from these sands; however, it is improbable that the cement forms a solid wall around the casing in the

oil sands that would shut out all the oil, for the reason that there is sufficient gas and movement of the cement to keep it from setting. Some operators advocate first mudding up the oil sands to keep the cement out and prevent circulation, but this procedure undoubtedly would prevent the return of the oil to a greater extent than the cement would.

The most difficult problem operators have to deal with is the case of a water sand lying between oil sands, where it is desired to produce oil from the lower oil sand and give the upper oil sand the proper protection from water. In many cases such protection would require two additional strings of casing. The first string being cemented above the water sand, the second being cemented below the water sand, and the third serving as the water string, the diameter of the hole would be so reduced as to make it impractical. Instances are known to exist where the intermediate water was excluded from the upper oil sand with one string of casing. In those instances the casing was cemented below the water sand, enough cement being used to reach above it and bind the casing firmly to the overlying shale. Then the casing opposite the upper oil sands was perforated and they were proved to be free from water.

For further detailed specifications of methods of excluding water from oil wells the reader is referred to the descriptions by F. B. Tough.[1]

Collapsing Strength of Steel Casing

The question of strength of casing to resist collapse is of vital importance to oil operators contemplating deep wells, because it must be remembered that after the well is completed it will sometimes stand nearly empty and therefore the casing will be subjected to the maximum pressure of the column of water outside it. The use of casing which is too light is false economy.

When a test of the water shut-off is made at a well, it is desir-

[1] F. B. Tough: Methods of Shutting Off Water in Oil and Gas Wells. U. S. Bureau of Mines, *Bulletin* 163, 1918.

able to bail the well down as far as possible without collapsing the casing, and the accompanying table showing the strength of various sizes and weights of casing is presented as a rough guide.

TABLE I

Size of casing (nominal)	Weight per foot, pounds (nominal)	Collapsing strength, pounds per square inch	Depth of water exerting pressure enough to collapse casing (feet)
4¼	16	4,715	10,880
4½	13	2,900	6,700
4½	15	3,605	8,320
5⅝	20	3,295	7,620
6¼	20	2,345	5,420
6¼	24	3,215	7,420
6¼	26	3,650	8,420
6¼	28	4,080	9,420
6⅝	20	1,980	4,570
6⅝	26	3,075	7,080
6⅝	28	3,490	8,060
6⅝	30	3,850	8,900
7⅝	26	1,945	4,480
8¼	28	1,660	3,840
8¼	32	2,150	4,960
8¼	36	2,635	6,080
8¼	38	2,880	6,640
8¼	43	3,510	8,100
9⅝	33	1,285	2,970
10	40	1,425	3,290
10	45	1,795	4,140
10	48	2,025	4,680
10	54	2,510	5,800
11	47	1,375	3,175
11	60	2,215	5,100
11⅝	40	835	1,930
12½	40	500	1,150
12½	45	750	1,730
12½	50	1,010	2,330
12½	54	1,215	2,800
13½	50	650	1,500
15½	70	795	1,840

The list is based on a great number of actual tests conducted by Prof. Reid T. Stewart (Vol. 27, Transactions American Society of Mechanical Engineers), and the figures for depth of water exerting pressure enough to collapse casing is the limit beyond which safe operations should not extend. A prudent operator would stop far short of the limit by applying a safety factor of two, or possibly one and three-fourths. In this list no account is taken of such underground forces as are sometimes reported to have cut off and carried casing to one side and out of reach of the drilling tools. It should be remembered that when any force is suddenly applied it is much more destructive than when gradually applied, and if a well were suddenly emptied of its fluid content, as in the case of a gas blow-out, the casing might collapse under a water pressure that it would have supported if the well were emptied slowly by a bailer or pump. The depth of water is of course sometimes much less than the depth of the well, and it is always important to note the level of the fluid which stands outside of the casing. Care of casing before it is used is of vital importance. Tests show that when the casing is slightly flattened, or out of round, collapse occurs most easily. In handling casing it is ferquently allowed to fall and become bruised or dented, thereby inviting collapse when it is later used in a well.

AMOUNT OF CEMENT NECESSARY

The amount of cement required to fill certain spaces in an oil well should be approximately known when a job is commenced and Table II, where the space is exactly stated, can be used for such a purpose. In actual practice the exact cavity may not be known. The table is based on the fact that a sack of cement, weighing about 100 pounds, will occupy about 1.1 cubic feet after being mixed with water and allowed to set.

Capacity of Casing and Tubing.—The amount of fluid contained in casing or tubing must be determined before certain cementing operations. Tables III and IV present the information in convenient form.

TABLE II.—LINEAL FEET FILLED BY ONE SACK OF PORTLAND CEMENT ALONGSIDE OF OIL-WELL CASINGS

(One sack equals 1.1 cu. ft. neat cement when set.)

Size of casing, inches		Diameter of well (excess over casing diameter)					
Nominal	Actual outside diameter	One inch	Two inches	Three inches	Four inches	Five inches	Six inches
4¼	4.75	19.2	8.8	5.4	3.7	2.8	2.2
4½	5.00	18.3	8.4	5.2	3.6	2.7	2.1
5⅝	6.00	15.5	7.1	4.4	3.2	2.4	1.9
6¼	6.625	14.2	6.6	4.2	2.9	2.2	1.7
6½	7.00	13.5	6.3	4.0	2.8	2.1	1.7
7⅝	8.00	11.9	5.6	3.5	2.5	1.9	1.5
8½	8.625	11.2	5.2	3.3	2.4	1.8	1.4
9⅝	10.00	9.7	4.6	2.9	2.1	1.6	1.3
10	10.75	9.0	4.3	2.8	2.0	1.5	1.2
11⅝	12.00	8.1	3.9	2.5	1.8	1.4	1.1
12½	13.00	7.5	3.6	2.3	1.7	1.3	1.0
13½	14.00	7.0	3.4	2.2	1.6	1.2	1.0
15½	16.00	6.1	3.0	1.9	1.4	1.1	0.9

TABLE III.—TABLE SHOWING CAPACITY OF TUBING, PER LINEAL FOOT, IN GALLONS AND CUBIC FEET

Nominal inside diameter, inches	Weight per foot, pounds	Actual outside diameter, inches	Actual inside diameter, inches	Capacity per foot	
				Gallons	Cubic feet
1¼	2.24	1.660	1.390	0.079	0.0105
1½	2.68	1.900	1.622	0.1078	0.0144
2	4.00	2.375	2.021	0.1661	0.0222
2	4.50	2.375	1.971	0.1582	0.0212
2½	5.74	2.875	2.461	0.2470	0.0330
2½	6.25	2.875	2.433	0.2420	0.0323
3	7.54	3.500	3.080	0.3870	0.5180
3	8.50	3.500	3.018	0.3720	0.0497
3	10.00	3.500	2.914	0.3460	0.0463
3½	9.00	4.000	3.558	0.5160	0.0689
4	10.66	4.500	4.022	0.6600	0.0882
4	11.75	4.500	3.980	0.6510	0.0870

TABLE IV.—TABLE SHOWING CAPACITY OF CASING, PER LINEAL FOOT, IN GALLONS AND CUBIC FEET

Nominal inside diameter, inches	Weight per foot, pounds	Actual outside diameter, inches	Actual inside diameter, inches	Capacity per foot	
				Gallons	Cubic feet
4¼	16.00	4.750	4.082	0.680	0.091
4½	12.85	5.000	4.506	0.830	0.116
4½	15.00	5.000	4.424	0.799	0.107
5⅝	20.00	6.000	5.352	1.170	0.156
6¼	20.00	6.625	6.049	1.490	0.199
6¼	24.00	6.625	5.921	1.430	0.191
6¼	26.00	6.625	5.855	1.400	0.187
6¼	28.00	6.625	5.791	1.365	0.182
6⅝	20.00	7.000	6.456	1.700	0.227
6⅝	26.00	7.000	6.276	1.610	0.215
6⅝	28.00	7.000	6.214	1.580	0.211
6⅝	30.00	7.000	6.154	1.546	0.206
7⅝	26.00	8.000	7.386	2.224	0.296
8¼	28.00	8.625	8.017	2.625	0.350
8¼	32.00	8.625	7.921	2.560	0.343
8¼	36.00	8.625	7.825	2.500	0.334
8¼	38.00	8.625	7.775	2.470	0.330
8¼	43.00	8.625	7.651	2.390	0.320
9⅝	33.00	10.000	9.384	3.600	0.480
10	40.00	10.750	10.054	4.130	0.552
10	45.00	10.750	9.960	4.060	0.543
10	48.00	10.750	9.902	4.020	0.537
10	54.00	10.750	9.784	3.900	0.522
11⅝	40.00	12.000	11.384	5.290	0.706
12½	40.00	13.000	12.438	6.300	0.843
12½	45.00	13.000	12.360	6.230	0.834
12½	50.00	13.000	12.282	6.140	0.821
12½	54.00	13.000	12.220	6.090	0.814
13½	50.00	14.000	13.344	7.280	0.973
15½	70.00	16.000	15.198	9.420	1.260

Waste of Gas.—Gas encountered during the process of drilling an oil well has, in the past, frequently been considered simply as a nuisance because the well owner was not in the gas business. Such an attitude has led to enormous waste of gas which was

either allowed to exhaust itself by flowing into the air or if possible was cased off and allowed to waste gradually through underground channels.[1]

Diminishing fuel supplies called forth public disapproval of such waste and also brought about conditions which made the collection of gas commercially profitable. The methods of preventing waste of gas are therefore worthy of careful consideration by many oil producers.

In a general way prevention of gas waste involves much the same procedure as is followed in preventing damage to oil wells by infiltrating water. In the latter case the aim is to identify water bearing formations and prevent their contents from entering the well, while in the case of gas the aim is to identify the sources and prevent it either from entering the well or in any other way escaping.

Two mechanical methods have been developed in order to save natural gas. The first and most expensive method involves landing and securely seating several strings of casing which will separate the various strata carrying water and gas. Preceding pages furnish details to be considered in such procedure. The second method depends upon the introduction of mud-laden fluid or slime behind a single string of casing, so that it will enter and seal all porous formations.

The use of mud-laden fluid has become quite general since its introduction by the U. S. Bureau of Mines in Oklahoma in 1915.[2] The popularity of the method has doubtless been in large measure due to the fact that it obviates many difficulties and makes it easier to drill through a heavy flow of gas and proceed with the search for oil. Careful investigation has not yet brought forth all the evidence that might be desired to prove that the conservation feature is entirely effective. Some instances have occurred where both the overlying gas and the

[1] W. R. Hamilton: Traps for Saving Gas at Oil Wells. *Technical Paper* No. 209, U. S. Bureau of Mines, 1919.

[2] J. O. Lewis and Wm. F. McMurray: The Use of Mud-laden Fluid in Oil and Gas Wells. U. S. Bureau of Mines, *Bulletin* 134, 1916.

underlying oil have been taken from a field developed by the mud-laden fluid process of drilling. In many other instances, however, the final reports deal only with the oil which has been recovered and fail to show definitely whether the gas was saved. However, the basic theory involved is so entirely reasonable that the burden of proof rests largely if not entirely upon opponents of the method. One instance of absolute proof of its effectiveness, as applied to water, is noted on page 99.

The principle involved may be thus briefly stated: The mud-laden fluid is a mixture of water and any clay-like material which will remain suspended for a considerable time. Sand or other small rock particles must not be a part of the mixture because they will quickly settle down and tend to leave only clear water. The consistency of the fluid varies, with the conditions of its use, between specific gravities of 1.05 and 1.15, and sometimes even 1.5. The mud-laden fluid enters the porous rock formations, gradually deposits its load of clay and seals the pores. This action is similar to that of a filter.

Muddy water is always used as the circulating medium with rotary tools. Mud-laden fluid, conforming to the foregoing specifications, is readily obtained by merely allowing the sand from the drill cuttings to settle before re-introducing the fluid into the well. Mud-laden fluid can also be used with cable tools by means of a special casing-head provided with pipe line connections and stuffing box. Mud-laden fluid can be run into an open well, and even in the face of a heavy gas flow it can be introduced into the well by means of a trap consisting of pipe and valves. The description of tools and operations by Lewis and McMurray is complete enough to guide all work, and need not be here repeated.

Exact specifications for mudding a well are difficult to formulate, and further experience may alter such rules as are here tentatively presented.

1. The mud must be entirely free from sand or grit.

2. Constant circulation of mud must be maintained during operations until the casing is ready to land. Just before the

casing is landed the exit of mud from the well must be stopped and pumping continued at a pressure of from 200 to 500 lbs. per square inch, until no more mud can be pumped into the well.

3. The casing must be landed in a thick bed of sticky clay. Before landing the casing a hole 2 in. smaller in diameter than the shoe must be drilled at least 3 ft. below the larger hole.

4. A casing shoe not less than 3 ft. long must be used. The outside diameter at the point of the shoe must not be larger than at any point above.

5. Proof should be obtained that the casing is securely and tightly landed. The well should be drilled about 5 ft. below the shoe, bailed to a specified depth and allowed to stand at least 24 hours.

Testing the Condition of Oil Wells

At various stages in the progress of drilling an oil well, it is necessary, if good work is desired, to test the mechanical condition of the well and casing.

Bailing Test.—The exclusion of water from an oil well is of prime importance. Tests designed to prove that water has been excluded will go far toward proving that the well has been properly drilled. Obviously the best test is to remove all water from the well and see if any more comes in. Sometimes conditions are so complex that such a simple procedure is not feasible. The following rules have been evolved from several thousand tests.

1. Measurements to the bottom of the hole and to the bottom of the casing shoe must be carefully checked before the casing is landed or cemented. A steel tape should be used in determining the distance that the sand line or drilling line "measures over."

2. Casing must be tested by bailing the well to a safe depth (see collapsing strength of casing, page 43) before drilling below the shoe. Old casing may collapse with less pressure than that indicated for new casing. Testing by applying pump pressure inside the casing will not always reveal leaks.

3. The removal of cement or other material in the casing by

drilling must be carefully done so as to avoid damage to the shut-off. The drill must be run merely far enough to go through the cement and below the shoe. A distance of from five to ten feet below the shoe would be ample. By drilling too far below the shoe complications may arise which will render a positive test impossible.[1]

4. Bailing should continue until all fluid is removed from the hole, unless there is danger of collapsing the casing. It is advisable to run the bailer until it brings up nothing by mud, and then after waiting an hour or more, to give the water which has accumulated on the inside of the casing time to run down, again apply the bailer. When a well is in such a condition that it can not be safely bailed dry, the fluid should be lowered to a certain depth, (depending upon pressure and strength of casing), by continuously running the bailer to that depth until no more fluid is brought up. A permanent target should be placed on the line to mark this bailing point. If both oil and water are present in a well which can not be bailed dry, it may be necessary to remove only the water by operating the bailer until it fails to bring up water. The bailing should then be discontinued for several hours, and again resumed to increasing depths until the point where it again picks up water is determined. At this point the well is ready for inspection, and the water may afterwards be removed by bailing from the bottom of the well, a record being kept of the amount bailed out. It may be necessary to repeat this process several times in order to determine whether the water is being exhausted. In the case of a high-pressure flow of gas, or in the case of heaving formation, it will probably be possible to test the well by pumping only.

5. When a tight or closed bailer is used in a deep well, some sort of valve or other outlet should be provided to relieve the gas pressure which may otherwise burst the bailer and endanger the lives of persons in the derrick.

A leaky bailer should never be used in testing.

[1] H. W. Bell: Source of Water in Oil Wells. Fifth Annual Report, State Oil and Gas Supervisor, Vol. 5, No. 8, pp. 23–43, February, 1920.

A proper test to determine whether or not a sand stratum carries oil or water can not be made unless water from all other possible sources is excluded.

When gas is flowing from a well in large quantities and under great pressure, it is sometimes difficult to determine whether or not water has been properly shut off. It has frequently been assumed that a constant flow of dry gas proved that the water had been shut off. There is, however, a possibility that the gas pressure may be great enough to hold back water which would otherwise enter the well. When the flow of gas is confined to a comparatively small outlet it will sometimes be entirely free from water while if the gas flow is entirely unobstructed very large quantities of water may accompany it. In such a case a final test must be postponed until the well is completed and its general condition noted for a considerable period of time.

It may, in some cases, be impossible to entirely exclude all water from an oil well. Under such conditions some reasonable limit to the permissible amount of water should be established. This amount will depend upon the average daily rate of oil production of other wells in the locality, and also upon how greatly water interferes with normal production. For instance, the limit considered reasonable in California is about 5 bbls. of water per 24 hours. This figure is probably excessive for some fields and too low for others. However, in any field or locality, conditions should be carefully studied for the purpose of establishing a limit, and therefore all tests should be reduced to a common basis of barrels per 24 hours.

The amount of water entering a well during a test is determined by the difference of level noted at the time of two separate observations. A diagram similar to Fig. 15 will be found convenient for computing the volume of water rising in various sizes of casing during various intervals of time.

Perforating Casing to Test Formations.—Where several strata of oil or water bearing formations are penetrated by a well it has sometimes happened that the upper strata have not been thoroughly tested. Such procedure leaves doubt as to whether

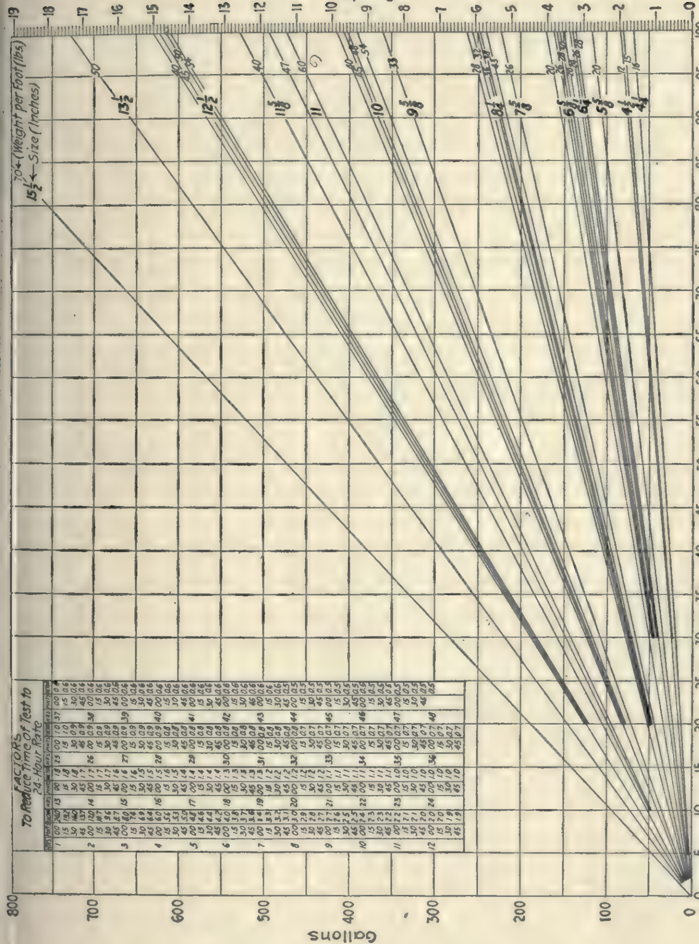


FIG. 15.—Diagram showing CAPACITY OF CASING in barrels and gallons. For use in reporting test of water shut-off.

or not some of these strata are susceptible of furnishing commercial quantities of oil, also as to whether water or gas have been prevented from passing from one stratum to another. The upper formations may be tested either by drilling another well into the shallow formations, or, in the case of deep wells, by perforating the casing which has shut off the formations. When the test by perforating the casing is adopted, it is assumed, of course, that some steps were taken, when the well was drilled, to permanently seal or separate the several strata. This sealing may have been accomplished by injecting cement or mud back of the casing, or the formations may have caved and settled around the casing.

At first glance it may appear extremely hazardous to delibertely perforate a string of casing which has been inserted in a well for the specific purpose of excluding water. However, this test has been successfully carried out in a number of wells, and in some instances has definitely proved that productive formations were cased off.[1] This process, in the hands of skilled workmen, is undoubtedly susceptible of considerable further development and use. The test should be preceded by a thorough study of the geology of the immediate neighborhood in order that it may be intelligently guided. Some method must be devised to prove that the perforating machine has actually cut through the casing and cement. One method is to paint the knife of the perforator before perforating, and to examine it after the operation for evidence of degree of penetration.

For a detailed presentation of the subject of perforated casing the reader is referred to the work of E. W. Wagy.[2]

Testing Casing For Leaks.—Where casing is inserted in a wel or the purpose of excluding water the first requirement is, o

[1] Fifth Annual Report, State Oil and Gas Supervisor of California Vol. 5, No. 7, pp. 5–9, January, 1920.

L. Vander Leck: Fourth Annual Report, State Oil and Gas Superviso of California, June, 1919, pp. 7–9.

[2] E. W. Wagy: Perforated Casing and Screen Pipe in Oil Wells. *Tech nical Paper* No. 247. U. S. Bureau of Mines, 1920.

course, that the casing shall itself be water-tight. Although this requirement would seem to be obvious it is frequently ignored. An excellent method of conducting this test is described by R. E. Collom.[1]

"Causes of casing leaks are usually one or more of the following: Insufficient tightening of casing, collapse, defective welds, corrosion, wear of drilling-line, or shifting formations.

"In a drilling well considerable time and expense can be saved by testing a water string, if cemented, before the plug is drilled out for test of shut-off.

"If this program is not followed, the test for water shut-off may be inconclusive and it may be necessary to again plug the shoe of the casing with cement or run a casing tester.

"By plugging in the shoe of the casing and making bailing tests, the existence of a casing leak and the rate of flow can be detected. By the use of a casing tester, the position of the leak, as well as the rate of flow, can be determined.

"A casing-tester, or swab-bailer as it is sometimes called, can be used to locate definitely any one of a number of leaks. There are a number of variations in the so-called swab-bailer or casing-tester. Figures 16 and 17 illustrate three of the varieties in common use. All testers have a closed bottom. The casing must be bailed free of fluid below the depth to be tested. The tester is run to a predetermined depth and allowed to stand for a given length of time. When the tester is removed, the amount of fluid therein can be measured and the rate of leakage reduced to terms of flow during 12 or 24 hour periods.

"When the position of the leak has been determined, the next thing to do is to repair it. The method of repair depends to a great extent upon the nature of the leak."

A detailed description of various steps to be taken in determining the source of water in oil wells, by H. W. Bell,[2] includes the following information:

[1] Fourth Annual Report of State Oil and Gas Supervisor of California, May, 1919, pp. 8–11.

[2] H. W. Bell. Source of Water in Oil Wells. Fifth Annual Report, State Oil and Gas Supervisor of California, Vol. 5, No. 8, pp. 37–40, Feb. 1920.

Packers Used in Locating Source of Water.—"Packers run into wells on tubing or casing and set in casing or formation are used to good advantage for testing source of water. The packer and casing act in the same manner as a cement bridge, and stop or retard the passage of fluid past

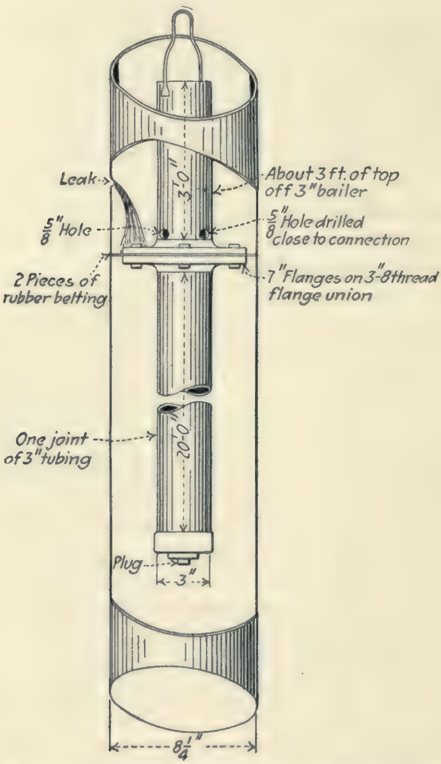


Fig. 16.—Sketch of SWAB-BAILER or CASING-TESTER to run in 8¼ in. casing. Method adaptable to all sizes of casing.

the point at which the packer is set. The subsequent testing by bailing or pumping is done below the packer, whereas in the case of a bridge the reverse is true. In other words, the packer eliminates the producible fluid from above and the plug or bridge eliminates the producible fluid from below.

"Packers are usually employed for testing with the idea of continued use for remedial purposes. The common packer makes use of an expanding rubber to effect a seal. Although the rubber is decomposed in time by oil and water, such packers are frequently left in wells for

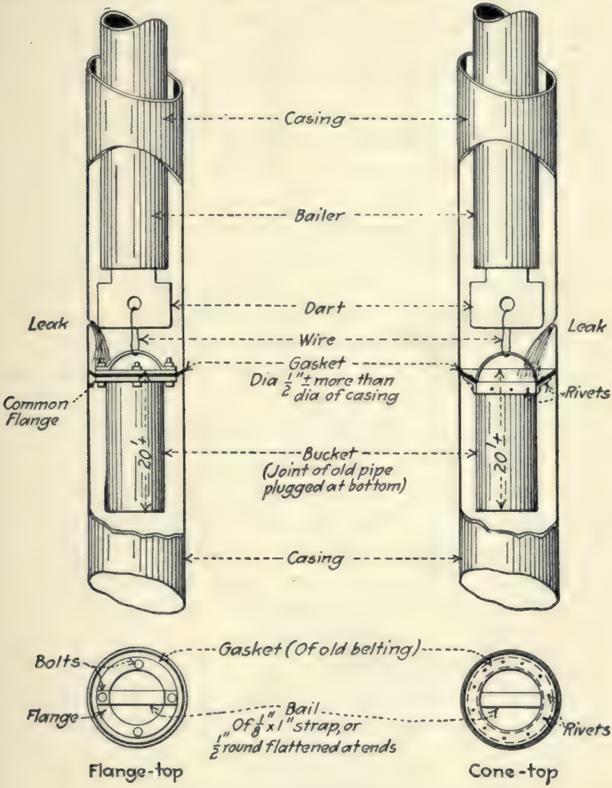


FIG. 17.—Sketch of swab-bailer or casing-tester.

permanent correction of water troubles. Hemp has been used successfully in this connection, and will probably endure longer than rubber. The efficiency of a packer may sometimes be increased by caving formation or by the addition of mud or sand put in from the surface.

Muddy Water Used to Indicate Leak in Casing.—"The point of entry of water into a well may sometimes be determined by using thin mud fluid

or muddy water. The well should be filled as high as practicable with muddy water, with a hole open to bottom or otherwise. The fluid should then be bailed off of the top, and a careful watch kept to note the thinning of the mud and the appearance of clear water. As the fluid level is lowered in the hole, the head of infiltrating water will again overbalance the fluid column in the well, with the result of thinning up the mud with clear water. As soon as the bailer has reached the point of inflow, it will pick up practically clear water. The point of inflow is thereby approximately located.

Dyes and Colorless Substances Used for Tracing Underground Flow of Water.—"Suitable dyes can sometimes be used to good advantage for indicating underground fluid connections and the direction of movement. Dye can also be used for testing the efficiency of a water string.

"The world war has greatly retarded the use of dyes since 1914, due to scarcity and prohibitive prices. Varying degrees of success have accompanied experiments in connection with oil field conditions. Some dyes are decolorized by the reducing action of petroleum compounds, and by hydrogen sulphide, or are absorbed by mud and formations. Such dyes are usually unsuitable for oil well purposes.

"The subject has not received the attention it merits, but it seems likely that experimentation will now be undertaken to determine the best dyes and best methods of application. Some of the dyes that are absorbed or reduced by crude oil may be used successfully when the fluid carries a large percentage of water. The following case noted in the Casmalia field by the writer will serve as an illustration. Seven pounds of red dye, which was probably one of the aniline group, was placed in the bottom of a well. Samples of water from the neighboring producing wells were taken frequently, but no color was at first noted. The production of water in this area is in excess of 50 per cent. One of the samples, after standing for several days, turned pink. The water produced in this area carries easily noticeable amounts of hydrogen sulphide, which gas was possibly responsible for the temporary decoloration of the dye. Upon standing exposed most of the gas passed off from the sample, and a regeneration of the color of the dye was effected.

"It is said that the dye eosin is not affected by hydrogen sulphide, nitric acid, magnesium sulphate, sodium hydroxide, alcohol or gasoline. The price and supply however, prohibit its use at present.

"The United States Geological Survey has used fluorescein extensively

for tracing the flow of underground waters in connection with water supply problems. It is said to be a delicate dye which is only slightly affected by the normal ingredients of natural waters; to be decolorized by acids and affected by some forms of unstable organic matter. A loss of color due to acidity can be restored by making the sample alkaline.

"A demonstration with dye is reported from the Midway field. Ten lbs. of red aniline dye was used, and the time required to appear in a neighboring well was four days. In another instance in the same field, 10 lbs. of green dye demonstrated underground connection between wells after two hours and forty-five minutes had elapsed. In this case the coloration at the point of sampling lasted about 30 hours. Although the flow of water from one well to another had been suspected, failures to demonstrate it have been made where 50 to 100 lbs. of dye was used.

"The chemical nature and intensity of a dye will influence the amount that should be used for a given set of conditions. In testing the efficiency of a water string 2 to 5 lbs. of good dye would probably suffice, while for use to show underground flow, 10 lbs. or more would be advisable. When testing a water string, the dye is put behind such casing and washed down with a stream of water. The pumping of the well should not be suspended. The appearance of dye in the production will indicate a casing leak or defective shut-off. When testing for underground connection, the dye should be released at the bottom of the suspected well, and this well remain shut down during the time of test.

"Prussian blue is reported to have been successfully used in a number of cases, and it seems to meet the general requirements of oil field conditions. It is a cyanide of iron, and the writer is not fully advised as to the effect that sulphur compounds may have upon it. It is, however, probably the most reliable and available dye for present use.

"It is understood that the underground flow of water has been traced by colorless substances which the water did not contain except in comparatively small quantities. For instance one of the rare elements, such as lithium, may be added in small quantity and samples from some other point tested by spectroscopic analyses. Or an excess of a compound, such as chlorides or sulphates, may be added and the samples tested by measuring the resistance to an electric current, or by chemical means.

Oil and Emulsion.—"The underground association of oil and water presents some interesting phenomena. Water is less viscous than crude oil and therefore finds easier passage to a well, with the effect of holding

the oil back in the formations. If water and oil are intimately mixed and agitated, an emulsion is formed. If a well produces emulsion and it be known to originate not by leak-back in the pump or by excessive working of gas in the well, the conclusion may be drawn that the water has entered the well through an oil stratum, or that the oil and water have passed a defective plug or bridge."

Final Test of Well by Pumping.—The final test to determine whether water has been excluded from a well, and also to prove its productiveness, is made by pumping. However, a careful operator will not fail to apply the other tests that may be made before completion, for the reason that the pumping test covers all the possible elements of improper construction, and in the event of adverse results it may be difficult to determine the exact cause of failure.

The details of a pumping test are important, and are set forth in a succeeding chapter under the head of "gauging."

CHAPTER III

ASSEMBLING OF INFORMATION RELATIVE TO UNDERGROUND CONDITONS

Underground conditions affecting the flow of oil into wells can only be conjectured after a careful consideration of the facts disclosed above ground. In the preceding chapter were outlined some of the more important facts which should be observed, and the methods to be followed in their collection were indicated. It will be noted that the information deemed necessary to a comprehensive understanding of this subject is composed of a great mass of apparently insignificant facts.

The information collected, step by step, as oil wells are drilled, soon becomes so voluminous that it is incomprehensible unless properly systematized. The method of systematizing the facts, as in all branches of scientific work, must be such that it will lead to the disclosure of their causes. This chapter presents methods which have proved useful in digesting and interpreting all available information.

Maps.—The first step which must be taken in the study of a tract of oil land is the preparation of a complete and accurate map. The elementary training of an engineer deals with the subject of surveying and mapping, and it is, therefore, unnecessary to here recount the details of such work.

However, the most necessary features of an oil field map deserve some notice because many carefully prepared maps fail to meet entirely the needs of the work at hand.

The scale of a detailed working-map should ordinarily not be smaller than 500 ft. to the inch. The largest scale required will seldom exceed 100 ft. to the inch. Maps compiled to cover large tracts of land containing many wells should not ordinarily be drawn to a smaller scale than 2000 ft. to the inch.

The position of all wells, irrespective of depth, degree of completion or operating condition, should be shown on the map. The number or name by which each well is known should also be shown, as well as the properly lines and ownerships, so far as they help to describe or identify wells. The elevation of each well at the derrick floor, should also be shown. Elevations should be as accurate as it is possible to measure the depths of wells; that is, within less than one foot. If sites for additional wells have been definitely chosen they should also be indicated, together with the ground elevation. Both the location and elevation of well sites shown on the map must be verified after the rig is built.

Topography shown by contours will frequently be useful, but is not necessary in all cases.

Symbols should be chosen to show the degree of completion of wells. Considerable latitude exists in the choice of symbols. In some localities certain symbols have come into common use and, unless they are entirely inappropriate, the local usage should

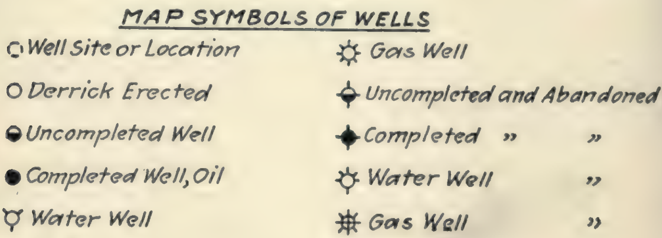


Fig. 18.

be followed. It will be found most convenient if symbols are chosen so as to show the progress of drilling by additional markings, thus making erasures unnecessary. The symbols shown in (Fig. 18) have been found practicable in extensive work, and may serve as suggestions.

The degree of accuracy required in oil field maps, or rather the permissible percentage of error, is governed by the uses to which the map is to be put. For instance, when a map is to serve

as a basis for making cross sections or peg models, the distances between wells may frequently be determined by measurement on the map. If the cross section or peg model is made on a scale larger than the original map, serious errors will be introduced by magnifying the original errors.

Graphic Logs of Wells.—After all the available information is recorded in a complete and carefully written log, it usually fails to present a clear and comprehensible mental picture of actual conditions, while a detailed sketch or graphic log, accurately drawn to scale, makes the information fully comprehensible. To obtain the greatest benefit from the use of graphic logs a number of details must be given careful consideration. In the previous chapter were stated numerous instances of how the mechanical or drilling conditions of a well affect the recorded observations of geological conditions. Therefore a sketch designed to present all available information must show the mechanical features as well as the geological record.

The vertical scale which has been found most useful in making graphic logs is 100 ft. to 1 inch. The width of each drawing should for convenience be between 1½ to 3½ inches.

Graphic logs are usually drawn on two kinds of material depending upon their purpose, *i.e.*, heavy cardboard or tracing cloth. The advantage of cardboard is that it can be more readily handled, and colored crayons can be quickly used to show various features. The advantage of using tracing cloth is that any number of duplicate copies can be quickly made, and furthermore several tracings can be quickly grouped in any desired position to make blue prints of cross sections. The advantages possessed by cardboard can be obtained by making blue prints or blue line prints on heavy paper.

More than ten thousand well logs have been drawn by the California State Mining Bureau on tracing cloth in accordance with the specimen shown in Fig. 19.

At the top of the drawing is shown the well name, its number and location.

The left hand side of the drawing notes all mechanical features,

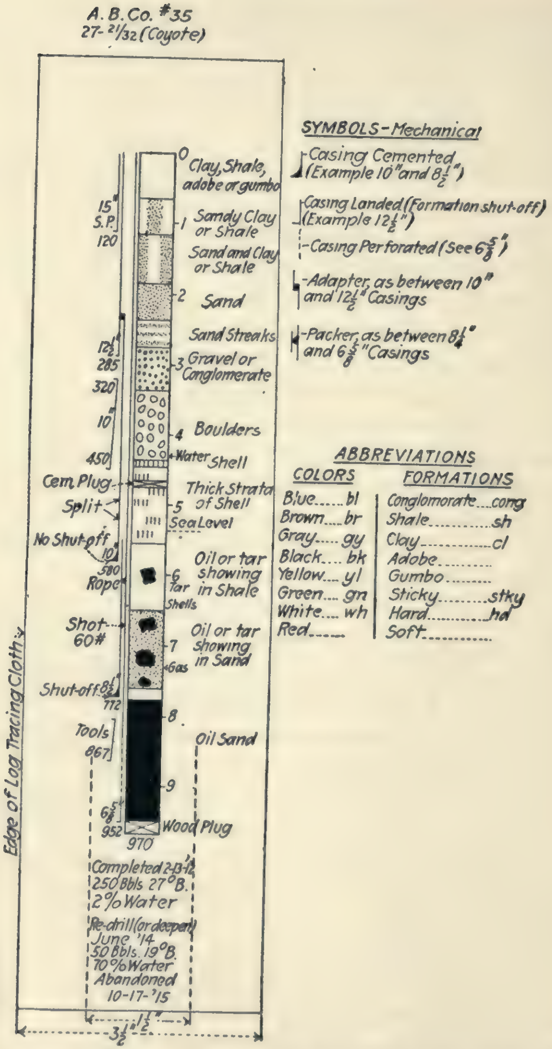


FIG. 19.—Graphic log of well. Specimen copy and conventional symbols.

and particularly the amount of casing in the well and its condition.

The right hand side of the drawing names or describes the geological formations which are symbolized in the log, and notes special features such as oil, gas, tar, water and fossils. The symbols shown here would, of course, heed revision to be applicable to some other localities.

At the bottom of the drawing are brief notes on the production of the well at the time of its completion, and also at other particular periods.

The time required to draw such a graphic log was found to average about two hours. As a guide and assistance to the draftsman, a drawing, showing the scale and having vertical lines, was pasted on the drafting board. The drafting board was 5 in. wide and from 30 to 40 in. long. A strip of wood nailed to the left hand side of the board projected far enough above the board to serve as a guide against which the triangle rested. The symbols were designed to follow the conventional system as nearly as possible, and were all made with one drafting pen, which saved time.

Graphic logs are filed most conveniently in special drawers, slightly deeper than the width of the drawing, and wide enough to hold logs of average length without folding. Cardboard folders should be provided of proper size to contain a dozen or more drawings, thereby providing for their separation and classification according to location of wells or other convenient grouping.

Cross Sections.—A graphic log does not serve its full purpose unless it can be compared with similar logs of neighboring wells. A comparison can be had by merely placing the two drawings side by side with their upper ends even. However, such a comparison is apt to be misleading because it takes no account of distance between wells, differences of elevation and dip of strata.

The best method of comparing and correlating graphic logs is to place them side by side and at such distances apart that their relative positions will be the same as exists at the wells. Such

an arrangement gives a cross sectional view of the underground conditions.

The horizontal and vertical scales should, in most cases, be the same, so that the picture presented to the eye is not distorted. The distances between wells can be scaled directly from a properly drawn map. The elevations of the top of wells furnish data for placing drawings in proper vertical position.

Many persons who realize the usefulness of cross sections have not given the subject sufficient study to enable them to arrange graphic logs properly. A frequent error consists in placing graphic logs in a single cross section, although the wells themselves are not located along a straight line on the ground. This error will frequently lead to such distortions that the resulting cross section is worse than useless. Elementary engineering training involves the study of geometry in three dimensions with the aim of solving exactly this sort of problem, so that further discussion of the subject seems superfluous.

Time and expense are saved in making cross sectional drawings by the use of graphic logs on tracing cloth. Such logs can be temporarily fastened in their proper positions upon a large piece of tracing cloth or even directly upon the glass of a blue-print frame. After sufficient blue-prints of a cross section are made the logs may be quickly rearranged for making prints of some other cross section. Such procedure saves making several duplicate drawings of individual logs, which might not be fully corrected or posted when changes occur at the well.

The name or title of a cross section seldom fully describes its location, therefore, a small-scale key-map of the locality should be printed in one corner of the cross section. A heavy line drawn upon the key-map will indicate the position of the cross section and the wells included.

An index to all cross sectional drawings is most conveniently made upon a small-scale map of the entire field, a line being drawn thereon to indicate the location of each cross section. Each cross section may also conveniently carry an index or serial number.

A filing system for cross sections should be provided, so that they can be preserved and also readily found. Ordinary letter files or drawers may be used for this purpose if the drawings are carefully folded with the key-map on the outside.

The value of cross sections is shown by the following oil field problem, which probably could not have been solved without them. The cross-section (Fig. 20) does not conform to the specification requiring that the horizontal and vertical scales should be the same. The distortion is here justified by the necessity of confining the drawing to a single page of the book. Some details, such as names of formations, are also omitted.

The wells were drilled in the order as numbered. The strata are not bent or deformed in this particular locality. In each well the 10-in. casing was intended to shut off the water occurring above the oil sands. In well No. 3 it was landed at a depth of 1880 ft., in conformity with successful results obtained at No. 1 and No. 2. However, the sand between 1980 ft. and 2016 ft. was found to contain some oil and considerable water, hence it was necessary to use more casing to shut off this water. Since some experimenting was necessary, two strings, the 8¼ in. at 2039 ft. and the 6⅝-in. at 2098 ft., were used. Had all conditions been known beforehand only one string would have been necessary, but when the 8¼-in. casing was landed and the well drilled deeper more water was encountered and the 6⅝-in. casing had to be used. The final oil string of casing, 4½ inches in diameter, was carried to 2351 ft., and upon testing the well was found to produce mostly water, so the bottom was plugged (using waste rope, iron lathe-cuttings and cement) up to 2265 ft. and the well again tested, when it was found to be free from water.

Since well No. 3 was one of the first wells in this locality to encounter water in the oil sands where oil was expected, careful work was necessary on the next well drilled, in order to verify conclusions drawn from evidence furnished at well No. 3. This was done an the neighboring wells, not shown on the drawing, and since similar results were found, the top sands in well No. 4. were shut off with the 10-in. casing at 2320 ft. The well was

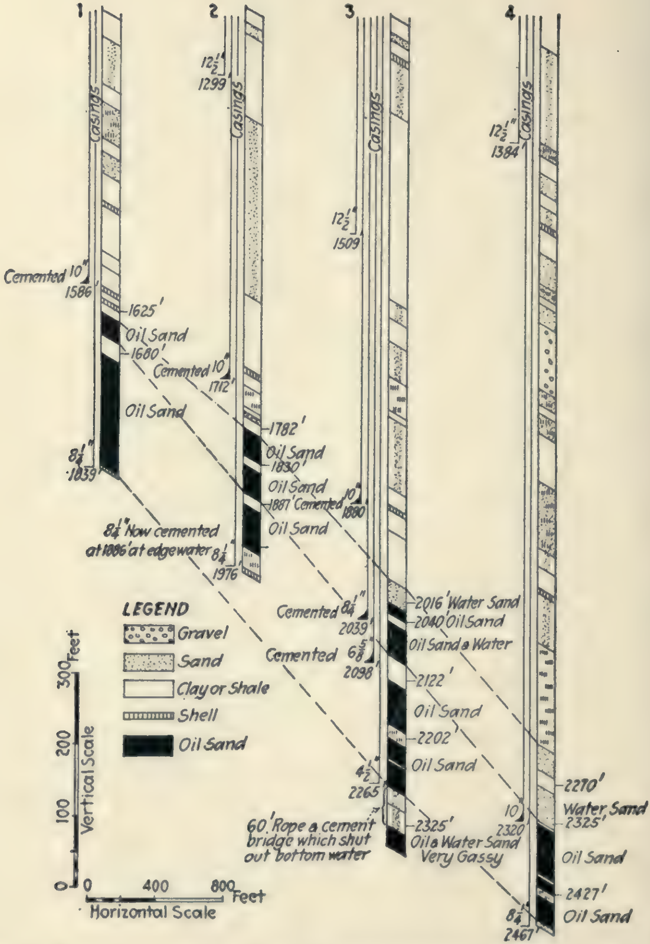


FIG. 20.—Cross-section showing underground relation of four oil wells.

drilled to 2467 ft. only, so as not to encounter the sand which contained water in well No. 3 between the 2325 and 2351-ft. levels.

After completion, all these wells produced clean oil for about a year, then well No. 2, began to show a little water, and about three months later showed about 80 per cent. There were three possible sources from which the water could come: from other wells through the oil sands, or from above the oil sand, or from the bottom sands penetrated. The drawing shows that the possibility of bottom water was slight. The possibility of water coming from above was tested by removing the 8¼ in. "oil string," putting a bridge or plug in the open hole between the bottom of the 10-in. "water string" and the top of the oil sand. After bailing the well dry above the plug no water came in, proving that the "water string" was not leaking at any point and was effectively excluding upper water. Therefore the natural presumption was that the water in well No. 2 was coming through the oil sand, and as the same sand showed both oil and water between 1980 ft. and 2095 ft. in well No. 3 it was concluded that the water was rising along the dip of that sand as the oil was removed. Such a movement is called the encroachment of "edge water." The 8¼-in. casing was again put in and cemented at 1886 ft., in the shale presumed to correspond to that found at 2091 to 2122 ft. in well No. 3, and 2318 to 2325 ft. in well No. 4. After pumping the well for about 10 days, the oil was found to contain less than one per cent. of water, proving that the water had been coming through the upper sands between 1782 and 1870 ft. After about four years the water commenced to show in well No. 1. This movement of water naturally follows the removal of oil and can not be stopped, but the particular sand affected can be kept separated from other productive sands.

It will be noted from the foregoing description of a cross section that more detail enters into its construction than is usual in the generalized or ideal cross sections accompanying geological reports.

Peg Models.—The relations existing between a number of wells can not be completely and clearly shown by a single cross sectional drawing, except where the wells are situated along a straight line.

Several cross sections can be made so as to cut the group of wells in all directions and thus present all phases of a situation. However, the separate drawings fail to give a clear and adequate picture such as can be had from a model.

Rods or pegs set up in their proper relative positions both vertically and horizontally, and colored to represent various formations penetrated by bore holes, have for many years been used in connection with mining operations. This method is particularly adaptable to oil wells and justifies a description of some general specifications which have been extensively used.

It must not be understood that models will entirely obviate the necessity for cross sectional drawings. The drawings can be made more accurately than a model, and are therefore absolutely necessary in many cases.

A convenient scale which will show all necessary details is 100 ft. to the inch. The horizontal and vertical scales should be the same, so as to avoid distortion.

Soft wood, such as sugar pine, is the most suitable material for a peg model on account of the ease with which it can be altered or added to. The wood must be thoroughly seasoned. A base board 1¼ inch thick will amply support pegs which are ½ inch in diameter.

It is usually more convenient to construct a model in separate pieces so that they can be separated to allow close observation of almost any locality. With the scale of 100 ft. to the inch, a quarter section of land is most conveniently covered by a single base board (26.4 inches square). A light skeleton table supporting four such boards may be moved about the room without greatly disturbing the arrangement of the boards.

The base map, showing well locations and numbers and also property lines can conveniently be drawn directly upon the

board. Its appearance will be improved if the boards are painted white.

Pegs not larger than ½ in. in diameter will leave open space sufficient for a general view. Larger pegs are more substantial but give undue prominence to the individual wells and obscure the general effect. Pegs should tightly fit into holes bored through the base board. Care in boring the holes is necessary in order that the pegs will stand vertically and securely.

Each peg should show all the important information furnished by the log of a well. The graphic logs, made according to the foregoing specifications, can be fastened directly upon the pegs. Blue prints will serve all ordinary working purposes, but the general appearance will be improved if white prints are used and the pegs are also painted white.

Blue prints are liable to shrink or stretch from the dimensions of the original drawings, and some precaution and ingenuity are required to lessen the effect of such distortion upon a model. The use of too much water in the paste for fastening the graphic logs to

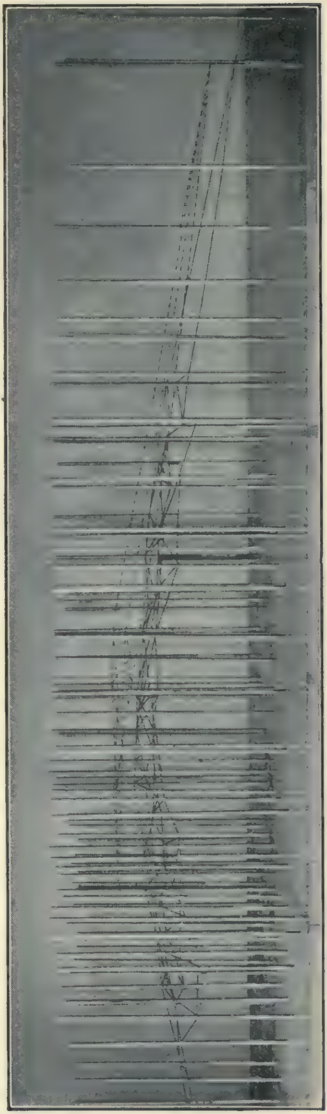


FIG. 21.—Photograph of a peg model. Coyote Hills Oilfield, California. The two series of strings show the two oil bearing strata and the dome shaped structure of the field.

the pegs will add to the error. Shellac has been used with good results.

After the pegs bearing complete graphic logs have been securely set in the base board, fine strings may be stretched from one peg to another in such a manner as to connect or correlate a stratum. The stringing of a model is the most important step in its construction. It will sometimes require many trial correlations before one is found which will stand the test of critical examination. A geologist familiar with the locality is in the best position to make such a correlation.

When a model is completely and correctly strung, its value will be apparent. All of the persons concerned in the underground condition of the wells will find, after studying the model, new ideas which would not have been discovered otherwise.

Pins with colored heads may advantageously be stuck in the pegs at important places, such as point of water shut-off or bottom of open hole.

Producing conditions, such as amounts of oil and of water can be conveniently shown by various colored labels or cards attached to the pegs.

Contour Maps of Underground Surfaces.—Upon an accurately constructed peg model, it is possible to see the various phases of geological structure. It is also possible to make direct measurements of depth, thickness and dip, at any point covered by the model. A peg model takes up considerable space and is not conveniently moved about, and, therefore, may not be readily available for all demands.

Contour maps of various strata furnish most of the information available on a peg model and such maps should be kept up to date.

A disadvantage in the use of contour maps is that their meaning is not self-evident, except to a person who is thoroughly accustomed to their use. Even in the hands of an experienced person, a contour map fails to impart as complete a mental picture as a model does. One advantage a contour map has is that it can be more accurately constructed than a model.

The method of constructing an underground contour map depends upon the simplicity or complexity of geological conditions. Where definite marker-strata are penetrated by wells, the only preliminary information necessary is the accurate location and elevation of each well and the depth to the marker-stratum. The foregoing data furnish the elevation of the marker-stratum at each well and fix the position of contour lines.

Where geological relations from well to well are difficult to trace it is necessary, before making a contour map, to make complete cross sections along many intersecting lines. Correct correlations may in some cases be impossible until after the stringing of a model. After complete cross sections have been correlated the elevations of various points in any given stratum are readily determined, and a contour map can be constructed.

The scale of contour maps will ordinarily be the same as that of the regular working map of the field.

A convenient procedure is to draw the contour lines directly upon a blue line print of the field map.

The contour interval will be determined by the dip of the formations, being smallest for flat dips.

The general methods of constructing and using topographical contour maps are applicable to underground maps.

Chart of Drilling Progress.—As wells are drilled, one after another, into productive formations changing conditions occur which affect production. In order to determine whether certain specific wells have caused a change it is necessary to devise some means of showing quickly and clearly the degree of completion of all the wells at any time. The following method devised by R. E. Collom[1] has been found most useful.

In order to compare the effect of wells which are in process of drilling, upon neighboring wells a chart showing drilling progress will be found more convenient than written records. The chart here presented differs from those ordinarily used in the fact that it

[1] Third Annual Report of State Oil and Gas Supervisor, California State Mining Bureau, *Bulletin* 84, pp. 196–197.

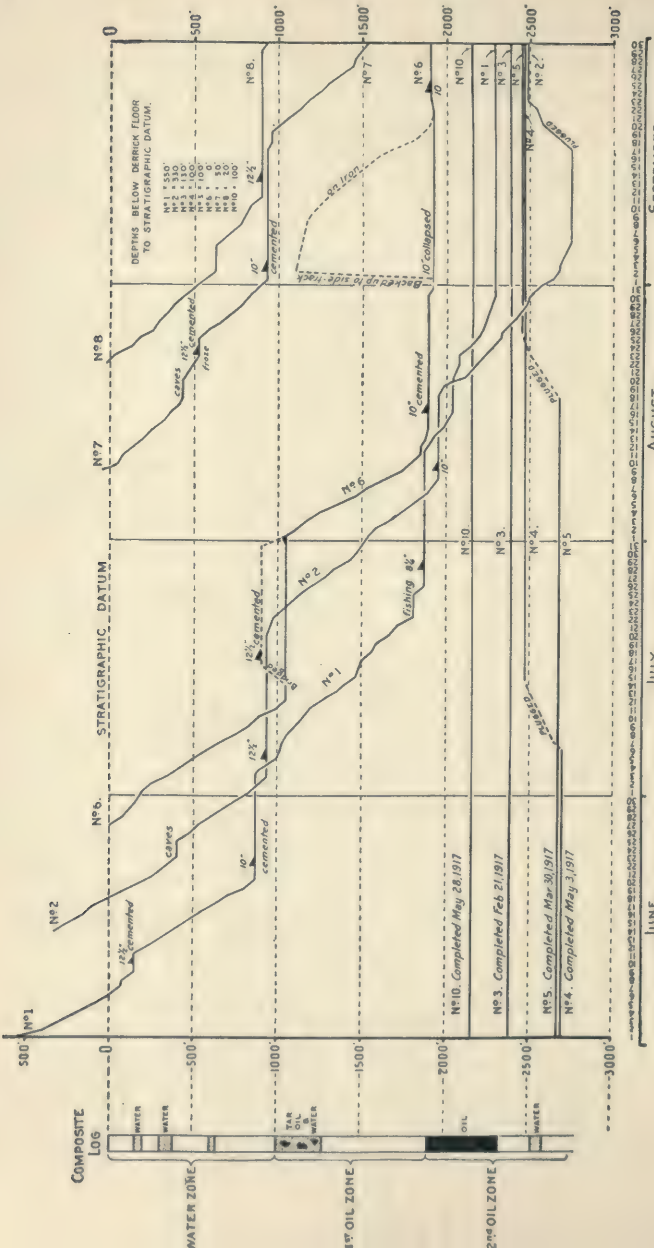


FIG. 22.—Chart of drilling progress of wells.

refers to distances from known strata rather than from the ground surface. It therefore directly compares geological information with drilling and production data.

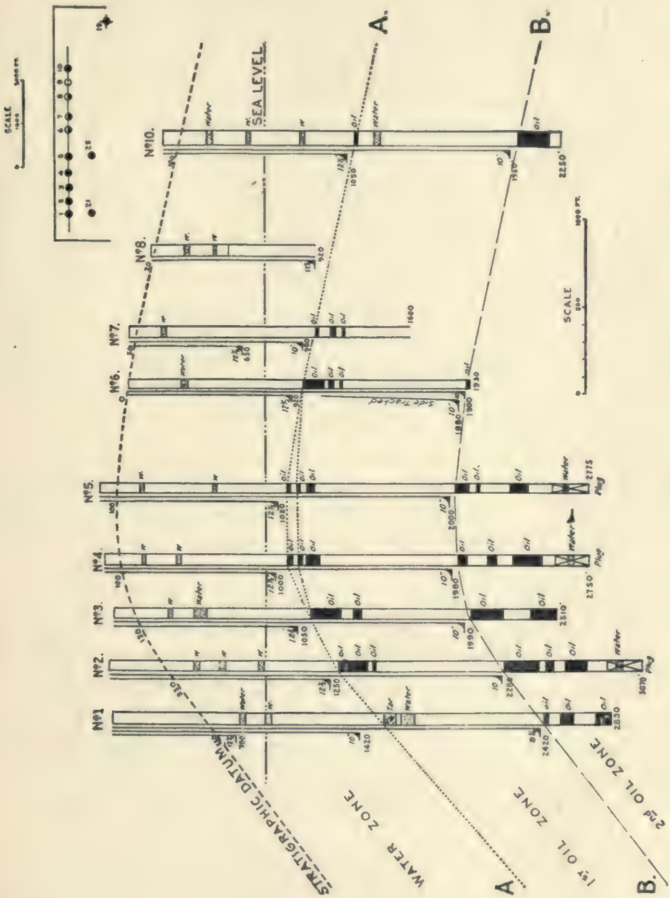


FIG. 23.—Cross-section of wells shown in progress chart of Fig. 22.

Referring to the accompanying cross-section of a group of wells, (Fig. 23) it will be noted that a line of correlation, "B", has been

drawn across the top of the oil sands of the "second oil zone." This line defines the stratigraphy of the formations.

With the idea of presenting a graphic history of drilling operations with respect to the stratigraphy of the formations penetrated rather than the respective depths below surface, a line parallel to the line of correlation "B" (see Fig. 23) is assumed at such a position that the drilling depths can be plotted downward from it. The distance between the line of correlation and stratigraphic datum can be chosen arbitrarily.

"In certain localities where some definitely known stratum [1] or formational marker exists—such as "Red rock," in the Coalinga East Side field, California, or "Bottom of blue shale," in the Casmalia field, California,—the line of correlation of this stratum, in the various wells may be used as stratigraphic datum.

"When such a stratum, as the one referred to, exists in a group of wells, one progress chart can be made for the entire group, irrespective of their location.

"On the accompanying cross-section stratigraphic datum is drawn through zero depth, that is derrick floor at Well No. 6, so that all corrections for differences from surface to stratigraphic datum in each of the wells will be plus. In this position also the drilling records with respect to the principal upper water strata and other formations of importance can be plotted.

"The data on the Progress Chart are shown with respect to time and depth. A convenient vertical scale is 100 ft. to 1 in. The depths drilled per day here shown would be unusual for anything but illustration. Progress in drilling is plotted from the daily tour records. It is not necessary, for plotting, to figure corrections between depths below surface and depths below stratigraphic datum. A graphic scale may merely be placed in such a position on the chart as to allow automatically for the distance of the derrick floor above or below the stratigraphic datum line.

"At the left end of the Progress Chart is a composite graphic log of formations between stratigraphic datum and the bottom of the stratigraphically deepest well in the group.

"All lines of correlation are horizontal on the Progress Chart. Dril-

[1] *Op. cit.*

ling operations in any well, plotted as the work progresses, can be referred across the chart to the composite log for a check on the formational progress of the work.

"As formations penetrated in certain wells may not be logged (although present) in a well being drilled, the summarizing of conditions (such as water sands, caves, shells, etc., in all wells of a group) into a composite log is a useful guide, although it should not displace the ordinary cross-section for accurate work.

"In preparing cross-sections, where the correlations are definitely known, stratigraphic datum can be used as the base line, instead of sea level. As on the Progress Chart, this will make the lines of correlation horizontal, and is a convenient method for comparison of relative depths, thickness of formations and other inter-related features.

"The Progress Chart gives a graphic history of operations in all the wells of a group. For example, reading up the vertical line for August 1, 1917, on the attached Progress Chart, it is easy to tell how many wells in the group were completed or in the oil sand at that date, also what wells were drilling or standing cemented.

"The Progress Chart could be used to advantage in the comparison of drilling records, either as to personnel of crews or methods of drilling. A comparison under this system would be more accurate, because of more nearly equal formational conditions, than a comparison by plotting to depths below surface."

CHAPTER IV

PRODUCTION OF OIL

The precautions taken to complete an oil well properly are for the purpose of obtaining the maximum output of oil. It therefore follows that careful attention must be given to the behavior of wells after their completion if full benefits are to be expected.

This chapter deals with the methods most suitable for observation and control of producing wells. The principles discussed will apply to the various methods and mechanical devices used in lifting oil from wells.

The amount of oil produced by an oil well corresponds to the gross receipts of the business. An accurate record of producing conditions is therefore as essential to the oil operator as is the cash register to a merchant. The records must be continuous from day to day, and besides showing the amount of oil produced must frequently include other data which affects production, such as amount of water, time of operation and depth of pump barrel. As in a small store, the owner of a small oil property may be in such close contact with the business that he need not record all the details. It will be found, however, that regular written records will assist even a small operator in the particulars mentioned and on a large property they are absolutely indispensable.

Gauging Output of Wells

There are several ways in which the amounts of water and of oil coming from a well may be determined. It is not always possible to get absolutely accurate figures. The following methods of gauging or estimating differ in accuracy and can be applied to properties of various types.

Actual Daily Gauge.—The most accurate figure is, of course, obtained by running the entire daily output of a well into a tank. The total volume can then be measured, the water drained off, and the remaining oil again measured and sampled for emulsion, or water in suspension. Such a system is applicable to wells producing high grade oil carrying a small amount of water and other impurities.

This system provides for the careful segregation and marketing of the more valuable grades of oil, and also supplies accurate facts as to the income received from the well.

Continuous Flow and Estimate.—A fairly accurate estimate of the amounts of oil and of water produced by a well can be made

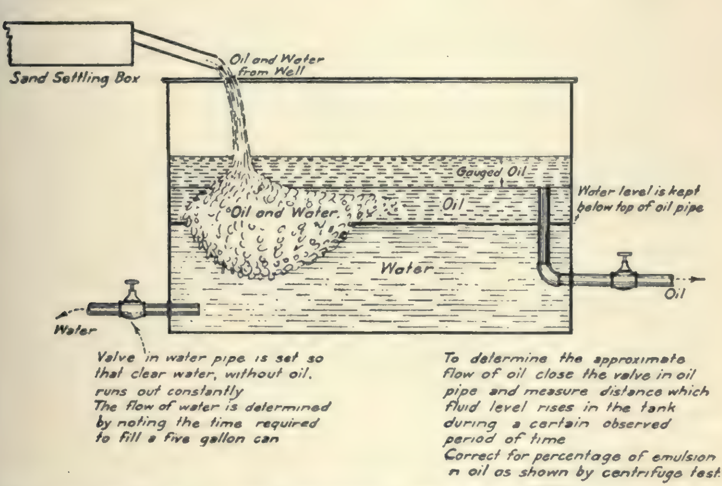


Fig. 24.—Sketch of tank and connections for gauging oil and water at a well.

by passing the entire fluid output through an automatic settling tank. A valve near the bottom of the tank is adjusted so that the water drains off constantly, while the oil passes out at a higher outlet. The quantity of water is determined by observing the time taken to fill a five-gallon can. The quantity of oil flowing is determined by closing its outlet valve and measuring the

rise of the fluid in the tank during a certain period of time. This method is adapted to large amounts of fluid, and particularly to free water, where the oil is not of the highest grade and not susceptible to great loss by evaporation. The accompanying sketch (Fig. 24) shows the arrangement of tank and connections.

A modification of this method may be applied to an open sump instead of a tank, but it is less accurate.

Sump Hole Estimate.—A rough estimate of the amounts of oil and water can be had by computing the cubic content of a sump hole and then observing the depth of fluid, either oil or water.

Lead Line Sample.—Some idea of output may be had by catching the flow from the lead line in a five-gallon can. The time taken to fill the can is observed and the total flow computed. The amount of water is determined by ascertaining its percentage by a centrifugal machine, commonly called a "centrifuge," or by merely allowing the water to settle. This method is inaccurate because the rate of flow of wells is seldom regular, and the proportions of oil and water are still less uniform.

Mere Inspection and Guess.—An experienced person can get some idea of the flow of a well by merely looking at the discharge end of the lead line. This method is subject to a possible error of from 100 to 200 per cent., or even larger. However, even this method, if regularly applied, would lead to an improvement of operating conditions at some properties.

Production Reports

Accurate observations of conditions accompanying oil production will not render the utmost value unless systematically recorded. Where complete records of production have been made over some considerable period of time, it is possible to make comparisons and find reasons for various occurrences. The form of such reports is not material so long as adequate information is supplied. The following form of monthly report has been widely and profitably used.

Section	Township	Range	Well No.	Barrels of clean oil	Barrels of water	Method of determining amount water	Percentage of water	Gravity of oil	Number of days well produced	Depth of pump barrel	Remarks

Due to the fact that the water frequently is not free to settle out, but is carried in the form of emulsion, the report blank does not fully meet the usage of the most careful operators. A more complete form can be devised about as follows:

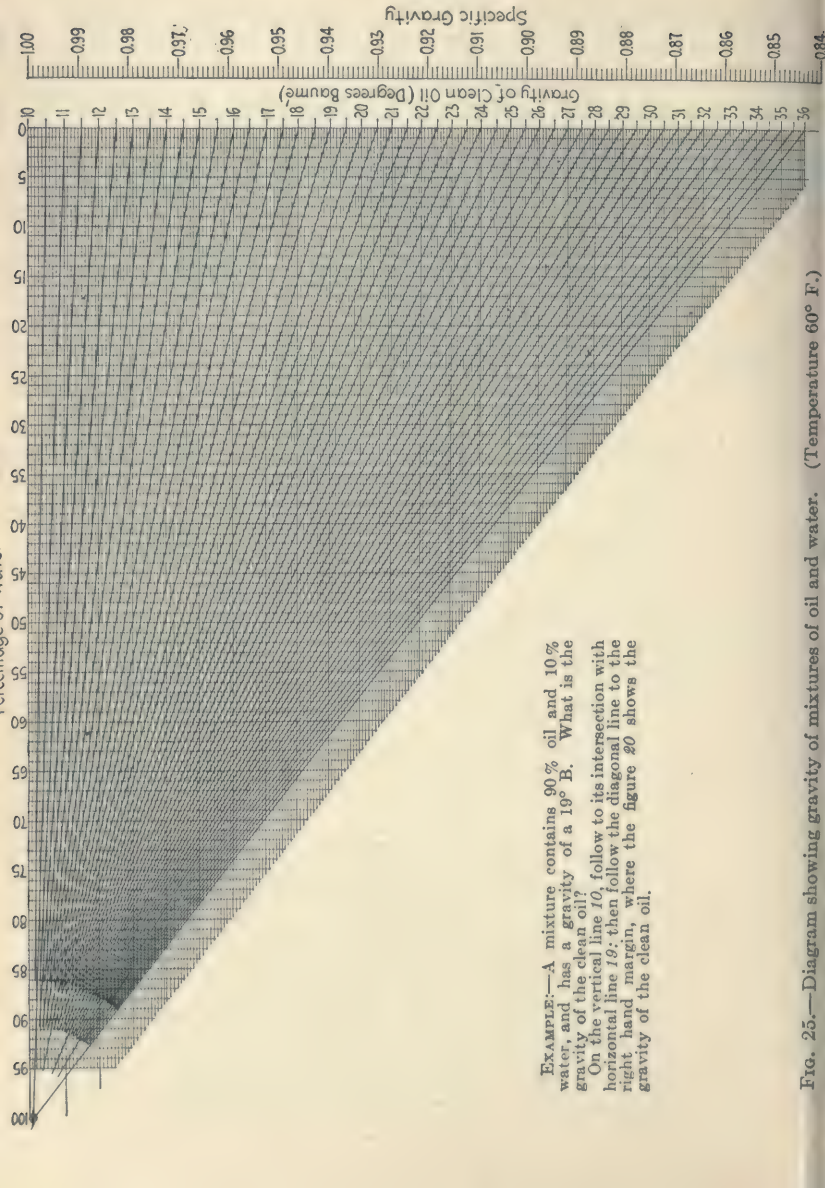
				Clean oil		Water							
						Drained		Suspended after draining					
Section	Township	Range	Well No.	Total for month (bbl.)	Gravity	Gauged	Estimated	Free	In emulsion	Total for month (bbl.)	Number of days well produced	Depth of pump barrel	Remarks (Such as deepening; redrilling; pumped daylight, etc.)

Total barrels oil.......... Total barrels water..........

Quality of Oil.—In some localities the oil produced is so uniform in character that no particular care need be taken to segregate the output of various wells.

Where there is great variation in the quality of oil from various sands and wells, it is of course important to separate the more valuable oil from the lower grades. In some cases this segregation requires analysis of each grade, while in other cases the specific gravity of the oil roughly indicates its value.

The specific gravity test is simple, being made by a special



EXAMPLE:—A mixture contains 90% oil and 10% water, and has a gravity of a 19° B. What is the gravity of the clean oil?

On the vertical line *10*, follow to its intersection with horizontal line *19*; then follow the diagonal line to the right hand margin, where the figure *20* shows the gravity of the clean oil.

FIG. 25.—Diagram showing gravity of mixtures of oil and water. (Temperature 60° F.)

hydrometer on the Baumé scale. The percentage of water mixed with oil is also readily determined by a "centrifuge."[1]

The specific gravity of a mixture of oil and water depends upon their relative amounts, and also upon the specific gravity of the oil. Where either of the two factors is known the other is readily computed, or read directly from a diagram such as shown in Figure 25.

The foregoing diagram is useful in the study and comparison of production reports dealing with varying grades of oil.

Use of Production Reports.—To be useful, production reports must be so designed that a study of them will lead to the cause of conditions which are either profitable or unprofitable. A concrete example of how production reports may be used to discover the source of water in a group of wells is afforded in the following description by M. J. Kirwan.[2]

"All of the wells were drilled several years before the period covered by these figures. Some of the dates and figures have been slightly changed from those shown in the original reports, so that it is possible to show the use of records with a limited number of wells and figures. There are, of course, many factors which influence the production of wells which do not show on a production report, such as their physical condition, and these factors must be taken into consideration when dealing with any given problem.

"The figures appearing on the regular monthly production reports show the total amounts of oil and water produced and the number of days the wells pumped, as follows:

[1] Methods for the Determination of Water in Petroleum and Its Products. I. C. Allen and W. A. Jacobs. *Technical Paper* No. 25, U. S. Bureau of Mines, 1912.

[2] Second Annual Report of State Oil and Gas Supervisor, California State Mining Bureau, *Bulletin* 82, pp. 27–30, 1918.

TABLE A.—PRODUCTION RECORDS TAKEN FROM THE MONTHLY PRODUCTION REPORTS

Month	Well No. 1C				Well No. 2B			
	Barrels of clean oil	Barrels of water	Per centage of water	Number days well produced	Barrels of clean oil	Barrels of water	Per-centage of water	Number days well produced
August	2,760	240	8.0	31	3,174	26	0.8	31
September	2,659	341	11.0	30	2,754	23	0.8	29
October	1,020	688	40.0	31	2,290	0	0.0	26
November	145	2,755	95.0	30	2,680	0	0.0	30
December	*	*	*	0	2,836	95	3.2	30
January	*	*	*	0	990	810	45.0	30
February	*	*	*	0	228	2,052	90.0	27
March	0	2,700	100.0	27	250	2,250	90.0	31
April	†	†	†	0	150	2,850	95.0	30
May	†	†	†	0	*	*	*	0
June	†	†	†	0	160	2,996	95.0	28

* Redrilling.
† Shut down.

TABLE A (*Continued*).—PRODUCTION RECORDS TAKEN FROM THE MONTHLY PRODUCTION REPORTS

Month	Well No. 3B				Well No. 4B			
	Barrels of clean oil	Barrels of water	Per centage of water	Number days well produced	Barrels of clean oil	Barrels of water	Per-centage of water	Number days well produced
August	3,850	268	6.5	31	3,550	1	0.0	31
September	2,290	126	5.2	28	3,320	0	0.0	30
October	2,340	87	3.6	30	3,820	0	0.0	31
November	2,600	72	3.0	30	3,336	34	1.0	30
December	2,806	94	3.2	29	3,285	81	2.4	30
January	2,340	110	4.4	31	2,606	918	26.0	29
February	1,680	420	20.0	28	430	157	30.0	6
March	480	1,920	80.0	27	600	3,400	85.0	27
April	708	2,496	78.0	30	255	3,470	93.2	30
May	260	3,150	90.0	31	257	3,143	93.0	31
June	180	3,220	95.0	29	*	*	*	0

* Redrilling.

TABLE A (*Continued*).—PRODUCTION RECORDS TAKEN FROM THE MONTHLY PRODUCTION REPORTS

Month	Well No. 3A				Well No. 2A			
	Barrels of clean oil	Barrels of water	Percentage of water	Number days well produced	Barrels of clean oil	Barrels of water	Percentage of water	Number days well produced
August	3,360	34	1.0	31	1,600	0	0.0	30
September	3,270	33	1.0	29	1,530	0	0.0	30
October	3,484	16	0.5	30	1,687	17	1.0	31
November	3,075	25	0.8	31	1,389	11	0.8	30
December	2,955	45	1.5	30	1,360	10	0.7	30
January	3,458	42	1.2	28	1,096	4	0.4	28
February	2,310	990	30.0	24	988	12	1.2	28
March	760	3,040	80.0	30	1,452	18	1.3	31
April	*	*	*	0	1,503	167	10.0	29
May	*	*	*	0	375	695	65.0	26
June	465	2,635	85.0	20	330	770	70.0	27

* Redrilling.

The figures when reduced to terms of daily production of oil are as follows:

TABLE B.—AVERAGE DAILY PRODUCTION OF OIL AND WATER, IN BARRELS, FOR EACH PRODUCING DAY DURING THE MONTH

Month	Well No. 1C			Well No. 2B			Well No. 3B		
	Oil	Water	Total fluid	Oil	Water	Total fluid	Oil	Water	Total fluid
August	89.0	7.7	96.7	102.0	0.09	102.9	124.2	0.0	124.2
September	80.8	11.3	92.1	95.0	0.8	95.8	81.8	4.5	86.3
October	32.9	21.9	54.8	82.0	0.0	82.0	70.8	2.9	73.7
November	4.8	90.2	95.0	89.3	0.0	89.3	80.9	2.6	83.5
December	*	*	0.0	94.5	3.0	97.5	96.7	3.2	99.9
January	*	*	0.0	33.0	27.0	60.0	75.5	3.6	79.1
February	*	*	0.0	8.4	76.0	84.4	60.0	15.0	75.0
March	*	100.0	100.0	8.1	72.6	80.7	17.8	71.0	88.8
April	†	†	0.0	5.0	93.0	98.0	23.6	83.2	106.8
May	†	†	0.0	*	*	0.0	8.4	104.0	112.4
June	†	†	0.0	5.7	107.0	112.7	6.2	111.0	117.2

* Redrilling.

† Shut down.

TABLE B (*Continued*).—AVERAGE DAILY PRODUCTION OF OIL AND WATER, IN BARRELS, FOR EACH PRODUCING DAY DURING THE MONTH

Month	Well No. 4B			Well No. 3A			Well No. 2A		
	Oil	Water	Total fluid	Oil	Water	Total fluid	Oil	Water	Total fluid
August......	114.5	0.0	114.5	108.3	1.0	109.3	53.3	0.0	53.3
September...	110.6	0.0	110.6	113.0	1.0	114.0	51.0	0.0	51.0
October.....	123.0	0.0	123.0	116.1	0.5	116.6	54.4	0.5	54.9
November...	111.2	1.1	112.3	99.2	1.0	100.2	46.3	0.3	46.6
December...	109.6	2.6	112.2	98.5	1.5	100.0	45.3	0.3	45.6
January.....	90.0	31.6	121.6	123.5	1.5	125.0	39.1	0.1	39.2
February....	71.7	26.1	97.8	96.2	41.2	137.4	35.3	0.4	35.7
March.......	29.6	103.0	129.6	25.3	101.3	126.6	47.0	0.6	47.6
April........	8.0	115.0	123.0	*	*	0.0	51.8	5.7	57.5
May........	8.0	110.0	118.0	*	*	0.0	14.4	26.7	41.1
June........	*	*	0.0	23.2	131.0	154.2	12.2	28.1	40.3

* Redrilling.

A careful study of the above figures would reveal many striking features, but in order to most clearly bring out their meaning diagrams are necessary. The diagrams here presented (Figs. 26 and 27) are almost self-explanatory, and show that well 1C was the first in the group to produce water, which quickly increased in amount accompanied by an equally rapid decrease in the amount of oil. It will be noted that the other wells in the group later followed a similar course. This fact indicates that well 1C is the source of the water trouble.

Diagrams based only on the water precentage, such as Fig. 27, can be more easily made and sometimes are sufficient to point out the origin of the trouble. However, such a diagram might be misleading for the reason that a well reporting a high percentage of water, but making only a small amount of oil, would be given equal prominence on the diagram with a more productive well. It will be readily seen that figures giving percentage mean but little unless accompanied by another figure which shows the true volume of water. The percentage of water in the wells under consideration is shown as follows in a diagram (Fig. 27).

It is of interest to note that some of these wells were covered by the cross section on page 25 which showed the significance of fluid

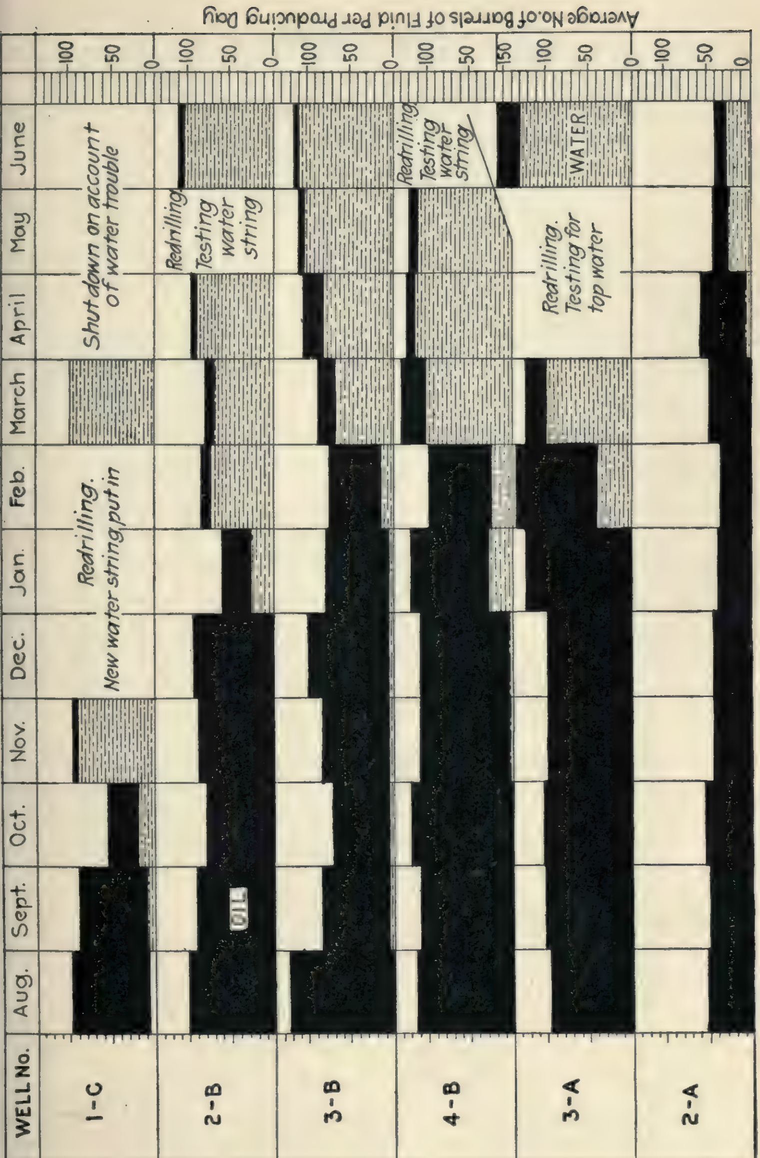


FIG. 26.—Diagram showing amounts of oil and water produced by certain wells.

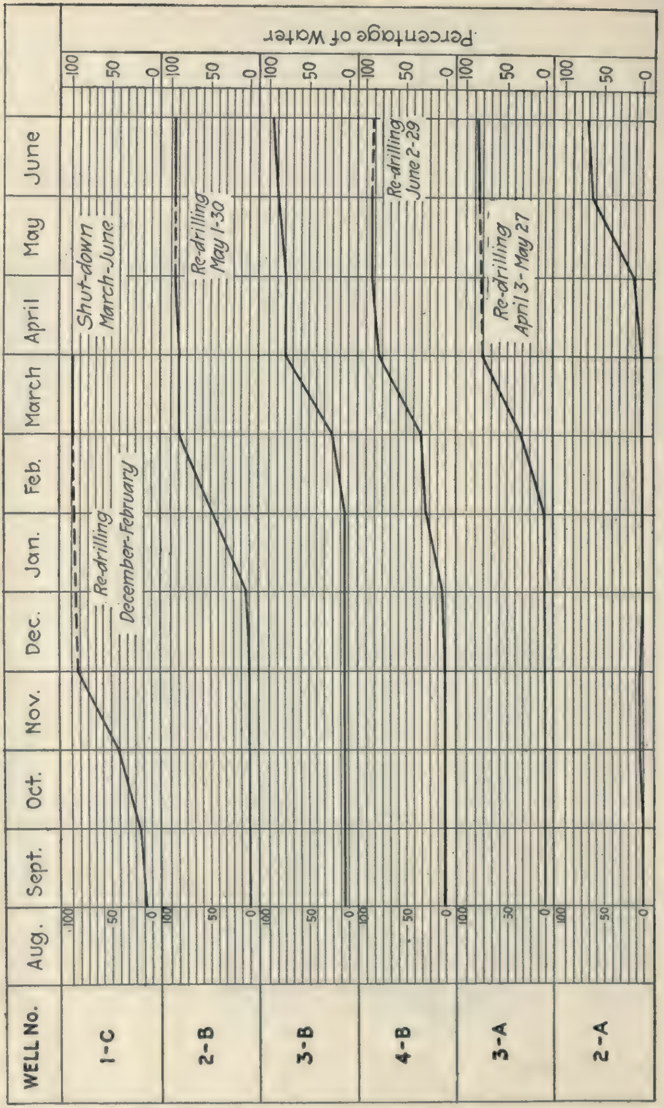


FIG. 27.—Diagram showing percentages of water produced by certain wells.

levels in wells. Both methods of investigation indicated the same well as the source of water.

Grapic Records of Well Production.—Investigation of the effect of neighboring wells upon each other requires that records

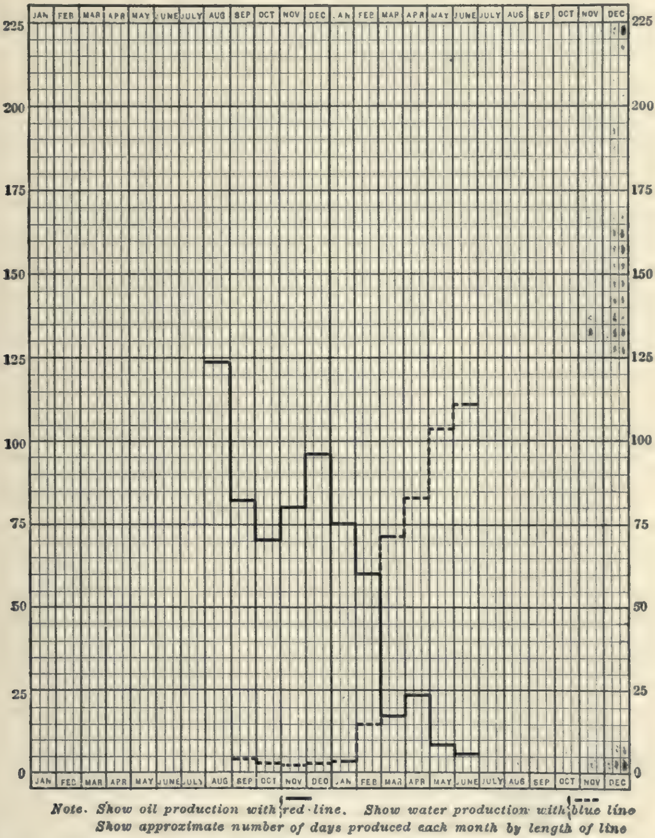


Fig. 28.—Graphic chart of average daily production of oil and water from individual well (barrels).

of their output shall be readily comparable. Such comparisons of any particular wells can be made if the graphic record of production of each well is on a separate drawing so that it may be placed alongside any other similar drawing.

The accompanying drawing, shown in Fig. 28, illustrates a form which has proved very useful. The record here shown is that of well 3B referred to in the two preceding figures.

The specially ruled cross-section form is printed on ordinary letter sized paper which simplifies filing.

The record can be quickly made with colored pencil or pen, and the process is so simple that no particular skill is required. An ordinary clerk can do the work.

In the particular instance illustrated the record so clearly showed the relation between the amounts of oil and of water that no doubt was left as to the cause of the decline in oil production.

Maps Showing Productiveness of Wells.—The productiveness of wells in various portions of a field will sometimes change on account of conditions which may be purely local. Water may be flooding a portion of a field, gas pressure may be exhausted, or some other local causes may affect the productiveness of the wells.

Intelligent control of such varying conditions demands that maps be periodically prepared so as to show the conditions at each well. The period of time elapsing between revisions of such maps will, of course, depend entirely upon the problem involved. Some work may require a new map each week, while in other cases annual maps may be sufficient.

Blue line prints of the regular field maps may serve as a basis for such work, and three or four symbols can be chosen so that no great time or skill is required in posting a map. A circle, drawn with a colored pencil, around a well may be used to indicate daily production of oil, gas or water, between certain limits. Two maps, one for oil and another for water, will clearly show the nature and extent of the damage to productive formations. The manner of enlargement of a flooded area will frequently indicate whether the damage is radiating from some improperly drilled well, or is gradually encroaching along the edge of an entire pool. The first case is susceptible of complete cure, while the second may be so controlled that the maximum amount of oil may be obtained. Examples of such maps will be found in the following chapter.

CHAPTER V

REPAIRING, DEEPENING AND ABANDONING WELLS

The increasing demand for oil will doubtless cause wells on many properties to be repaired for the purpose of increasing production. A great many oil fields have been developed having regard for nothing except immediate production. Such procedure has usually resulted in leaving considerable quantities of oil underground. In many cases, wells can be put into such condition that the remaining oil may be profitably extracted.[1]

Previous Records.—The first step towards repairing an old well is to gather all available information as to its present physical condition. It is also useful to gather information as to methods of drilling employed and behavior of the well while producing. Ordinarily, it will be found difficult or impossible to obtain complete and authentic information in regard to wells which it is proposed to repair. Where complete records have been kept it is quite likely that the owner has also kept the wells in good condition.

The foregoing chapters have dealt with the records which should be kept during the development of an oil property, and a review of those requirements will indicate what sort of information should be sought in regard to an old property. Frequently the search for information will lead through old letter files and account books. No possible source of information should be overlooked, as a single old letter may reveal some fact which was not considered important at the time the well was drilled but which may serve as a clue to general underground conditions.

Conditions in some fields interfere with production to such an extent that frequent repair work is necessary if wells are to be

[1] Casing Troubles and Fishing Methods in Oil Wells. Thomas Curtin *Bulletin* 182, U. S. Bureau of Mines, 1920.

kept producing at their utmost capacity. All such repair, deepening or redrilling work, should be recorded with as much care and detail as is given to a complete log of a new well. The repair work on a well can not be conveniently recorded on a printed form because each repair job must meet the special conditions encountered therein. A daily diary made up from the regular daily drilling reports will serve most purposes.

The use of old records as a guide to repairing the wells on a property involves the same steps that are followed in planning new drilling. The records must be summarized and arranged so that comparisons can be made; this involves maps, graphic logs and cross sections.

There are many instances on record where an undeveloped oil sand has been found in an old well simply by the evidence afforded by cross-sectional drawings of the locality. Subsequent work has frequently led to profitable production when water was excluded from such sands and they were otherwise placed in condition to yield their oil content.

The deepening of old wells so as to increase production by draining lower sands may be considered merely as an extension of the original development plan. The problem involved is to determine the position and probable productiveness of the lower formations, and these facts are determined by the use of cross-sections and production reports of previous wells.

In deepening a well due consideration must be given to the upper oil and gas formations. Unless the shallow formations are positively known to be exhausted, they must be protected against water lying either above or below.

Abandonment.—Wells are ordinarily abandoned for one of two general reasons; either because oil is not present in commercial quantities or because the physical condition of the well is such that it is permitting damage to oil sands in the vicinity.

Lack of oil may be the result of natural cause; that is, barren territory, or because of its exhaustion by artificial means.

If the locality has been *positively proved* to be barren of oil almost any means of abandonment may be justifiable, unless

other valuable natural resources are present, such as water, which must be protected against contamination.

Positive proof of non-productiveness of formations should always be demanded before the abandonment of wells. Many wells have been drilled and abandoned in such manner that the owner had no real information of the nature or value of formations upon which he had spent money for exploration.

If strata are known to exist which should be protected against infiltrating water or escaping gas, a well must be abandoned in such manner as to practically replace the impervious strata which have been penetrated. In other words some sort of impervious plugs must be placed in the well at points between the porous strata which are to be protected.

The easiest method of plugging a well is to fill it with mud fluid which may fill and seal all porous formations. Evidence is not plentiful to prove that this method is thoroughly effective, although some state laws approve it.

There are two methods of plugging a well with clay or mud; first, by mixing the clay with water in the well, and second, by mixing the clay and water at the surface and introducing the mixture into the well.

In describing the two methods G. McGregor says:[1]

"In the first method cable tools are used, being allowed to swing at the particular spot where it is desired to mud. The clay is then shoveled dry, or slightly moistened, into the top of the casing along with a constant stream of water. The water serves the double purpose of preventing the clay from "bridging" when it strikes the fluid, and also to a certain extent increasing the head of water in the casing, thus helping to carry the clay outside the casing and into the formation. The action of the tools swinging in the open hole is similar to the action of rotary drill-pipe, and as the clay settles down around the tools it is pounded back into the formation. Care must be taken that the tools do not become "mudded up" or that circulation does not stop while clay is being put in."

[1] Method of Mudding Wells in the Kern River Field. G. McGregor, Second Annual Report, State Oil and Gas Supervisor, California State Mining Bureau, *Bulletin* 82, pp. 87–90, 1918.

With the second method, various mechanical devices are used, such as a concrete mixer, to mix the clay and water. Some kinds of clay may be mixed sufficiently by merely throwing a strong stream of water against the clay bank.

Where old records are not complete and it is desired to plug wells in order to prevent water from entering them, mud has been found useful. Its use makes it possible for the tools to enter caving sands which could not otherwise be penetrated, and furthermore, the flow of water into the well is at least checked until some sort of solid plug can be put in place. It is necessary to reach the original bottom of the well and to split or destroy the casing so that the mud will have free access to the walls of the well.

Mud is sometimes forced into a well under a pump pressure of several hundred pounds per square inch, either through tubing or directly into the casing, fittings being provided at the top of the casing so that pressure can be applied to the mud. The mud is forced down until no more can be put in. In some cases circulation will be established to the surface, outside the casing, while in other cases no such surface evidence appears.

The following rules have been applied to many abandonments with a view to affording protection which could be tested to some extent.

Rules for Abandonment of Wells

1. In most cases sufficient casing should be left in a well to serve as a conductor from the ground surface to the point of shut-off. This requirement is based on the fact that it is frequently impossible to prove immediately and directly the effectiveness of plugging. It may be necessary to note the behavior of neighboring wells for a considerable period of time before it is shown that plugging has been effective. In some cases the condition of surrounding wells may demonstrate that plugging was not effective, and that further work is necessary at the abandoned well. The well could not be economically re-entered if all the casing had been removed. Furthermore, in soft formations it

does not pay to attempt to pull casing below the shoe of the next larger casing, as ordinarily only one or two joints of casing in contact with the walls of the hole can be recovered.

2. It is generally required that cement plugs be placed between various zones of oil or gas producing formations, in order to prevent the possible passage of water from one to another. In most wells it will be necessary to remove or shoot the casing between the depths at which plugging should be done, so that cement may reach the walls of the well. Wells which have sidetracked casing require a larger shot than those which have not. The casing in a well, between the shoe of the water string and a point at least 15 ft. below, should be pulled out or broken up by shooting, and the well should be plugged with cement for at least 20 ft. up into the water string.

3. In case of effective water shut-off, wells which do not have suitable formations in which to plug below the shoe of the water string, should be plugged (inside of such string) for at least 20 ft. directly above the shoe.

4. Each cement plug put into a well must be allowed to set at least 24 hours (and a longer time is advisable) after which time it must be determined that the cement has properly set before further plugging is done.

5. When a well is producing "bottom" water, the level at which fluid (water and oil) stands in the well should be accurately determined both before and after plugging. If possible the well must be plugged in a formation which will separate the water bearing formation from the overlying oil or gas bearing formations. The well must be tested by bailing to determine the effectiveness of the plugging. After such test has been made plugging should continue as indicated in rules 2 and 3.

6. When a well is making "top" water around the shoe of the water string, it will be necessary, in addition to the plugging between formations as required in rules 2 and 3, to place a cement plug in a suitable formation directly below the water string. If a suitable formation for the plug is not present, the water string should be shot or removed above the shoe at a

point opposite an impervious formation, and a cement plug should be placed tightly against the formation where the casing was shot or removed.

7. When a well is making "top" water through the water string it should be plugged as provided in rules 2 and 3.

8. When a well penetrates "intermediate" water below the water string, it should be plugged in a formation which separates the water bearing formation from the overlying and underlying oil or gas bearing formations. The depth to the fluid level should be measured, and a test made as indicated in rule 5.

9. When a well penetrates "intermediate" water above the shoe of the water string, and mud-laden fluid or cement has been effectively used for the protection of oil or gas bearing formations back of the casing, the water string should not be disturbed unless it is proposed to put in cement plugs between oil and gas bearing formations. Where the original protection sought by mud or cement was ineffective, it will be necessary to shoot or rip the water string at places where plugs will be required to separate oil or gas bearing formations. To test the effectiveness of the original protection, the water string should be perforated or ripped opposite the oil or gas bearing formations. If the test demonstrates that proper protection was obtained, the casing should be plugged to points at least 10 ft. above and below the perforation or ripping, in order to seal the openings in the casing. A water string which protects oil or gas bearing formations behind the casing by means of cement and mud, may be cut off (not shot) about 20 ft. above the shoe of the next larger casing. A cement plug should then be placed at the top of the casing.

10. When the source of water can not be definitely determined it will be necessary to use all the methods provided for every possible source.

When plugs are placed in an old well it is essential that the casing be removed or shattered so that the plug will bond with the walls of the hole, otherwise open channels between the casing and the wall may remain. Thorough ripping of the casing may sometimes be sufficient, but if the casing can be actually removed

from the portion of the well involved there is greater assurance of thorough plugging. The removal of the casing is best done by cutting it into five-foot lengths, and as each section is cut off it should be split several times, and as nearly as possible from end to end. As they are cut off these ripped sections can be pounded down, or crumpled, with the drilling tools.

Methods of Shooting Wells

In order to allow the setting of plugs it is most advantageous to shoot wells where oil and water bearing formations are penetrated by casing which can not be removed. It is necessary to shoot wells which have one or more strings of sidetracked casing (which may serve to conduct water into or between oil-bearing formations) in order that all holes may be converted into one large cavity, which must then be plugged to prevent the passage of water. It sometimes becomes necessary to first shoot with a small amount of explosive to create a "pocket" in which to place a charge large enough to obtain the desired results. In cases where the "pocket" has been made torpedoes of comparatively short lengths are connected by a wire so as to allow them to rest alongside of each other in the hole.

The method of shooting wells for repair work, such as has been mentioned, is somewhat different from the common practice in shooting new wells and is well described by M. J. Kirwan as follows:[1]

"Previous to the year 1910 oil wells in California were generally shot in the following manner:

"A shell, or container, was made of ordinary galvanized, light sheet iron. Sticks of stock 60 per cent. dynamite, usually from ⅞ to 1⅛ inches in diameter by 8 inches in length, were loaded into the shell which was lowered into the well to the desired depth by the sand line. The charge of dynamite was detonated by the use of a blasting cap lighted with a fuse. The length of the fuse was regulated so as to allow

[1] Methods and Reasons for Shooting Oil Wells. M. J. Kirwan, Second Annual Report, State Oil and Gas Supervisor, California State Mining Bureau, *Bulletin* 82, pp. 82–84, 1918.

sufficient time to lower the shell to the desired shooting depth before detonation. The diameter of the shell was governed by the size of the casing through which it had to be run and the length of the shell by the amount of dynamite used.

"In some instances a piece of casing was used for a container of the dynamite. This container was lowered into the well to the desired depth by an attached string of tubing extending to the surface. The charge of dynamite was exploded by dropping a squib-shot through the tubing. Squib-shots usually consist of a short piece of pipe about one inch in diameter containing one or two sticks of dynamite with cap and lighted fuse attached. The explosion of the squib-shot detonated the main charge of dynamite previously lowered into the well.

"The foregoing described methods of shooting wells are still used in some cases. The results obtained by employing such methods have, in many instances, been unsatisfactory, and in some cases detrimental to the well on account of casing having been shot at the wrong depth as a result of premature explosion. There are cases in which workmen engaged in shooting have been killed or injured, while using one of these methods, on account of accidental explosions at the surface.

"The modern method of shooting oil wells is accomplished by the use of a specially prepared blasting gelatin, an explosive much safer than dynamite or nitroglycerin, on account of its insensitiveness to heat, friction or concussion. Straight blasting gelatin is a nitroglycerin and gun-cotton composition, and is not especially adapted to well shooting on account of its tendency to so harden shortly after manufacture that it can not be made to conform to the size or shape of the desired shell or container.

"Blasting gelatin, for well-shooting purposes, is prepared by the addition of wood pulp in certain proportions in order to make it sufficiently plastic that it can be properly shaped for the container.

"Electric detonators, which are especially prepared to withstand the pressure to be contended with in oil-well shooting, are embedded in the blasting gelatin and then connected in series so as to insure a simultaneous explosion of the entire charge. The torpedo or container, when loaded, is lowered into the well to the shooting depth by the sand line, and the waterproof leading wires from the electric detonators are connected to a blasting machine, or power circuit, at the surface. The charge of gelatin is then detonated by electric current at the desired moment.

"Following is a table giving the amount of blasting gelatin held by various sized torpedoes per foot. The diameter of the torpedo is regulated so as to carry the desired amount of explosive per foot. The largest diameter of a torpedo used is usually about one inch less than the diameter of the smallest casing through which it has to pass.

Diameter of torpedo in inches	Pounds per foot	Diameter of torpedo in inches	Pounds per foot
1	½	4½	11¾
1¼	9/10	5	14½
1½	1¼	5½	17½
1¾	1¾	6	21
2	2¼	6½	24¾
2¼	2¾	7	28¾
2½	3½	7½	33
2¾	4¼	8	37½
3	5¼	8½	42½
3¼	6	9	49
3½	7	9½	53
3¾	8¼	10	58
4	9¼		

"The amount of explosive used should be regulated by the physical condition of the well between the shooting depth and height of the fluid above the shooting point, and the results desired."

Use of Mud Fluid in Abandonment.—Mention has been made of the scarcity of positive proof of the effectiveness of the use of mud-fluid in sealing formations. An instance of actual demonstration at Coalinga, California, under the supervision of R. D. Bush, may therefore be worthy of complete description. The location of the well is shown by the map (Fig. 29).

The accompanying graphic log (Fig. 30) shows the condition of the lower portion of the well just previous to the last redrilling and abandonment work, the latter having been decided upon after mechanical troubles made it doubtful whether the 8¼ in. casing could be successfully recemented so as to exclude top water. The 10 in. casing was originally the water string, and

the well produced oil for several years from the sands below it. Later, edge water appeared in the upper sands and was shut off with the $8\frac{1}{4}$ in. casing at a depth of 1885 ft.

In preparation for the mudding and abandonment, 1864 ft. of $6\frac{5}{8}$ in. and 1826 ft. of $8\frac{1}{4}$ in. casings were pulled out, and another string of $8\frac{1}{4}$ in. casing was carried to 1980 ft. and the

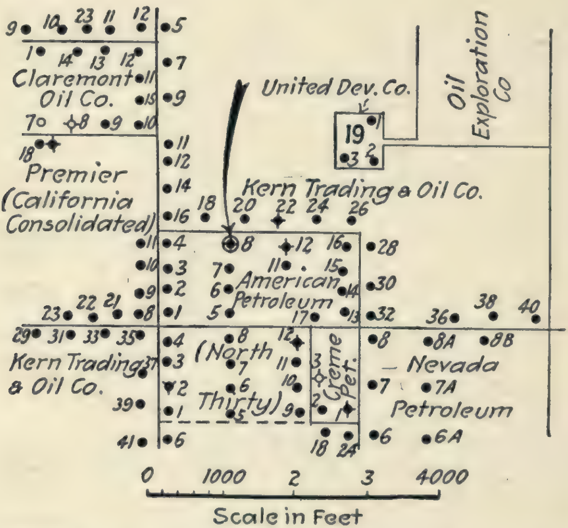


FIG. 29.—Map showing location of a well abandoned with mud fluid. (Coalinga, California.)

well cleaned out to 2004 ft. Mud fluid was obtained by mixing the surface formation, which was fairly good clay containing a small amount of fine grained sand, with water. A 40-horsepower boiler and Gumbo Buster pump were set some 900 ft. from the well, where the mud was mixed by circulating the fluid through the pump and discharging it through a hose into a shallow reservoir made by plowing the ground and banking up the sides. The sand settled to a great extent before the fluid reached the suction box at the pump. The pump discharged directly into

the top of the $8\frac{1}{4}$ in. casing at the well through a 2 in. pipe line. The work at this plant was attended to by one man, with occasionally an extra helper, and the work at the well by two drilling crews of two men each.

No figures are available as to the amount of material pumped into the well, but some idea may be gained by a statement of the approximate time during which mud was being introduced into the well. The total time consumed in mudding, moving casing, plugging and cleaning out, was 46 days of 24 hours each, and on every day except six mud was pumped into the well a portion of the time, occasionally with the 2 in. valve wide open, but generally only barely open, allowing just enough fluid to run in to keep the hole full (but not running over between the $8\frac{1}{4}$ and 10 in. casings). By conducting the work in that manner the oil sands took all the mud put in, the quantity gradually decreasing until the hole stood full under the hydrostatic pressure only. A casing-head was then put on, with packing clamps between the $8\frac{1}{4}$ and 10 in. casings, and more mud pumped in until the pressure was raised to 200 lb. per square inch. At the end of the operations the pump pressure fell only 20 lb. in one hour while standing.

FIG. 30.—Portion of the graphic log of a well abandoned with mud fluid. (Coalinga, California.)

During the first sixteen days the $8\frac{1}{4}$ in. casing was held at 1927 ft., and the sand at that point mudded until it required pump pressure to force more mud into the well. The casing was then lowered to 1976 ft. and the sands below 1990 ft. mudded in the same manner. Plugs composed of brick and rope were

then put in from 2004 ft. up to 1949 ft. The casing was then pulled up to 1784 ft. and the upper sands mudded under pressure.

During the first portion of the work the mud fluid was mixed rather thin so that it would be carried a considerable distance from the well and be deposited in the sand voids, thus building up an artifical and impervious body of clay around the well. As the sands became clogged with mud, the mud-fluid was thickened so that the final colum of fluid standing in the well up to the surface was of maximum density, and its hydrostatic pressure greater than that of the water in any stratum of sand. It was thus aimed to confine all water to the sands in which it occurred.

That the mud fluid traveled away from the well when the fluid was thin was shown by the fact that muddy water appeared on the fifth day in the production of wells Nos. 7, 6 and 5 in succession, being more pronounced in the nearest one, No. 7 (distant 332 ft.), and least in No. 5 (distant 1000 ft.) and disappeared after the fluid was thickened, and pump pressure was required to force it into well No. 8.

The result of the oil and water production at neighboring wells is shown by the following figures taken at the time of abandonment, 60 days later, and two years later.

AVERAGE DAILY PRODUCTION (BBL.)

Well	At completion of abandonment		Sixty days after abandonment		Two years after abandonment (Nov., 1919)	
	Oil	Water	Oil	Water	Oil	Water
No. 7..........	16	418	19	219	10	33
No. 6..........	12	187	22	190	23	174
No. 5..........	12	373	19	249	19	202
Totals.......	40	978	60	658	52	409

The mud had settled after two years time, so that a weighted measuring line would only go down to a depth of 1708 ft. The fluid remained standing to within 10 ft. of the surface.

Examples of Repair Work at Oil Wells

The practical value of the various methods and principles enumerated on previous pages may be clearly illustrated by actual examples.

Coalinga Field, California.—One of the first detailed investigations made under the California State law, governing the methods of drilling and maintaining oil wells, was in the Coalinga field, in 1917.

Good records of well conditions were available.

Certain repair work was done which resulted in increasing the production of oil and decreasing the amount of water produced. The official order reads in part as follows:[1]

"Water in excessive and damaging quantities is at present entering the oil sands of several wells situated within a radius of approximately one-half mile from the Creme Petroleum Well No. 1.

"The excessive amount of water is probably due to improper conditions existing at more than one well in the area mentioned. Relief can only be had by treating all the wells under a single comprehensive plan, for the reason that they are intimately related underground.

"The investigation began with the assumption that the damaging conditions complained of were confined to the immediate vicinity of the Creme Petroleum Well No. 1, but it shortly appeared that the conditions were widespread. Forty-nine wells in the neighborhood, were producing a total of 1822 bbl. of oil and 2996 bbl. of water per day (nearly two barrels of water to one of oil). The scope of the examination was therefore extended to cover some 63 wells which are listed herewith, together with figures showing the average daily amounts of oil and of water produced by each well.

"These figures are for the month of December, 1916, unless otherwise noted. The tabulation also shows the number of days each well produced during the month.

[1] Creme Petroleum Well. Second Annual Report, State Oil and Gas Supervisor, California State Mining Bureau, *Bulletin* 82, pp. 225–335.

PREMIER OIL COMPANY
SEC. 24, T. 20 S., R. 14 E.*

Well No.	Days	Bbl. Oil	Bbl. Water
8	6	23	4
9	6	39	1
10	9	17	4
11	31	4	1

KERN TRADING & OIL COMPANY
SEC. 25. T. 20 S., R. 14 E.

Well No.	Days	Bbl. Oil	Bbl. Water
35	20	36	Last ten days all water.
37	31	76	76
39	19	43	30

KERN TRADING & OIL COMPANY
SEC. 19. T. 20 S., R. 15 E.

Well No.	Days	Bbl. Oil	Bbl. Water
16	28	19	2
18	31	17	7
20	19	19	0.4
22	0	..	Idle since Oct., 1914, account of small production.
24	21	25	0.8
26	29	46	1
28	28	63	5
30	9	22	7 *July, 1916
32	9	31	72
36	31	202	50
38	4	171	15 Nov., 1916

NEVADA PETROLEUM COMPANY
SEC. 30, T. 20 S., R. 15 E.

Well No.	Days	Bbl. Oil	Bbl. Water
3	31	63	118
4	31	11	1
5	31	11	2
6	25	11	124
7	0	..	Idle since Dec., 1914. Water possibly not shut off.
8	31	12	0.2
4A	13	43	67
5A	15	36	56 Nov., 1916.

			Working on well in Dec. Set packer account of water.
6*A*	31	46	7
7*A*	0	..	Working on well testing water shut off.
8*A*	31	55	228
8*B*	31	64	8

American Petroleum Company

Sec. 19. T. 20 S., R. 15 E.

Well No.	Days	Bbl. Oil	Bbl. Water
1	31	19	168
2	31	12	3
3	31	9	8
4	31	13	7
5	31	51	131
6	31	34	63
7	31	47	28
8	31	31	0.9
11	0	..	Recemented, Sept., 1916, account "Top" water.
12	0	..	Shut down June, 1911, account small production.
13	25	24	72
14	31	35	41
15	31	108	38
16	31	87	10
17	25	27	17

AMERICAN PETROLEUM COMPANY

SEC. 30, T. 20 S., R. 15 E.

WELL NO.	DAYS	BBL. OIL	BBL. WATER
1 (N 30)	31	10	22
2 (N 30)	0	..	Abandoned.
3 (N 30)	31	31	27
4 (N 30)	0	..	Shut down
5 (N 30)	31	19	1
6 (N 30)	31	116	39
7 (N 30)	31	28	214
8 (N 30)	31	44	104
9 (N 30)	13	5	431 Nov., 1916
10 (N 30)	31	28	43
11 (N 30)	31	18	284
12 (N 30)	0	..	Abandoned
18	31	6	132
22	31	22	250
23	0	..	Idle since Oct., 1915. (Bridge over oil sand account "Top" water.)
24	0	..	Idle since Aug., 1915.

CREME PETROLEUM COMPANY

SEC. 30, T. 20 S., R. 15 E.

WELL NO.	DAYS	BBL. OIL	BBL. WATER
..	0	..	Idle since 1913.
..	0	..	Idle since 1913.

"For the purpose of comparison the wells are segregated into three classes according to their average daily production of oil:

First: Under 20 bbl. per day.
Second: Between 20 and 40 bbl. per day.
Third: Over 40 bbl. per day.

"This segregation is shown on the accompanying map (Fig. 31).

"For the purpose of comparison the wells are also segregated into three classes, according to the average daily production of water. The same figures are used for this classification as before mentioned (under 20, 20 to 40, and over 40), and this segregation is shown on the accompanying map (Fig. 32).

"Study of the map upon which the wells are segregated according to the amounts of water produced shows the probable area within which the damage complained of is confined.

"Such an area is shown on both of the accompanying maps, its limits, or boundary lines, being in general determined by the location of wells making less than 20 bbl. of water per day.

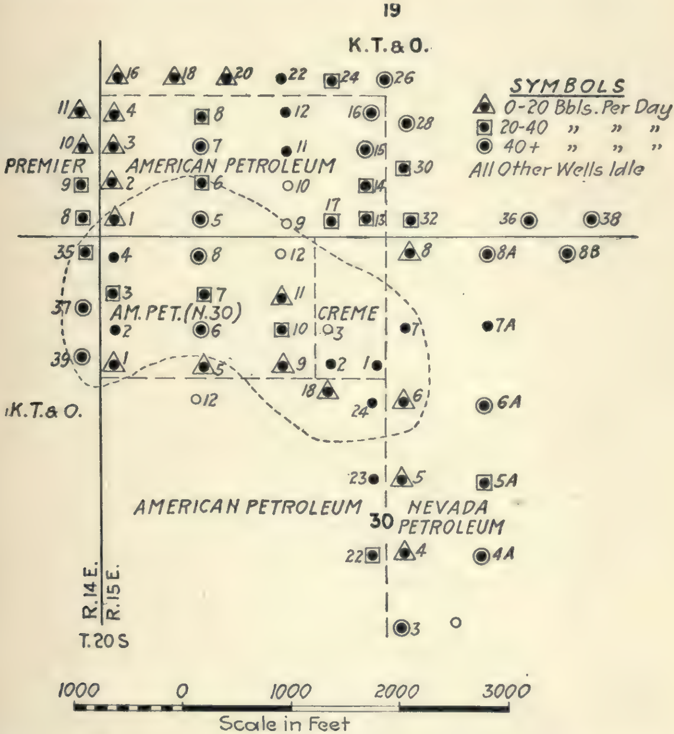


Fig. 31.—Map of portion of Coalinga field showing average amounts of *oil* produced daily by various wells in December, 1916.

"Wells situated within the area of damage total 23, and are shown in the following list, arranged according to the dates at which a marked increase of water occurred. These dates are determined from written reports furnished by the various companies, with the exception of the Creme Petroleum Company. In all of the wells, unless otherwise noted,

damaging amounts of water have continued, or have increased, since the dates given herewith.

Name of well	No.	Sec.	T.	R.	Date of marked water increase	Average daily production Dec., 1916, bbl.	
						Oil	Water
American Petroleum	5	19	20	15	Nov., 1910	51	131
American Petroleum	6	19	20	15	Jan., 1911	34	63
Creme Petroleum	2	30	..	..	July, 1911	Probably water afterwards eliminated.	
American Petroleum	1	19	20	15	Sept., 1911	19	168
American Petroleum	12(N-30)	30	20	15	Feb., 1912		
American Petroleum	8(N-30)	30	20	15	Apr., 1912	44	104
American Petroleum	2(N-30)	30	20	15	June, 1912		
American Petroleum	1(N-30)	30	20	15	July, 1912	10	22
American Petroleum	4(N-30)	30	20	15	July, 1912		
Creme Petroleum	1	30	20	15	July, 1912		
American Petroleum	6(N-30)	30	20	15	Aug., 1912	116	39
American Petroleum	7(N-30)	30	20	15	Sept., 1912	28	214
Nevada Petroleum	6	30	20	15	Nov., 1912	11	124
American Petroleum	18	30	20	15	Jan., 1913	6	132
American Petroleum	24	30	20	15	Jan., 1913		
Nevada Petroleum	7	30	20	15	Apr., 1913		
American Petroleum	9(N-30)	30	20	15	June, 1913	5	431
Kern Trading & Oil	37	25	20	14	Aug., 1913	76	76
Kern Trading & Oil	39	25	20	14	Oct., 1913	43	30
Kern Trading & Oil	35	25	20	14	Oct., 1913		
American Petroleum	3(N-30)	30	20	15	Mar., 1914	31	27
American Petroleum	11(N-30)	30	20	15	Mar., 1914	18	284
American Petroleum	10(N-30)	30	20	15	July, 1914	28	43
					Totals...	520	1888

"Of these 23 wells recent production figures are given herewith for 15, and from them there is a daily production of 520 bbl. of oil and 1888 bbl. of water (nearly four barrels of water to one of oil).

"In addition to the previously mentioned facts the investigation has covered the underground conditions as shown by the well logs. The large amount of data involved in this phase of the work cannot be readily summarized here, and in fact can be shown only by means of a model. It may be well, however, to note at this time that the investigation has thus far disclosed that the present condition of Creme Petroleum

Well No. 1 is almost identical with that of American Petroleum Well No. 2 (N-30), Sec. 30, American Petroleum Well No. 4 (N-30), Sec. 30, American Petroleum Well No. 12 (N-30), Sec. 30, Nevada Petroleum Well No. 7, Sec. 30, in that all five wells are plugged above the oil sands.

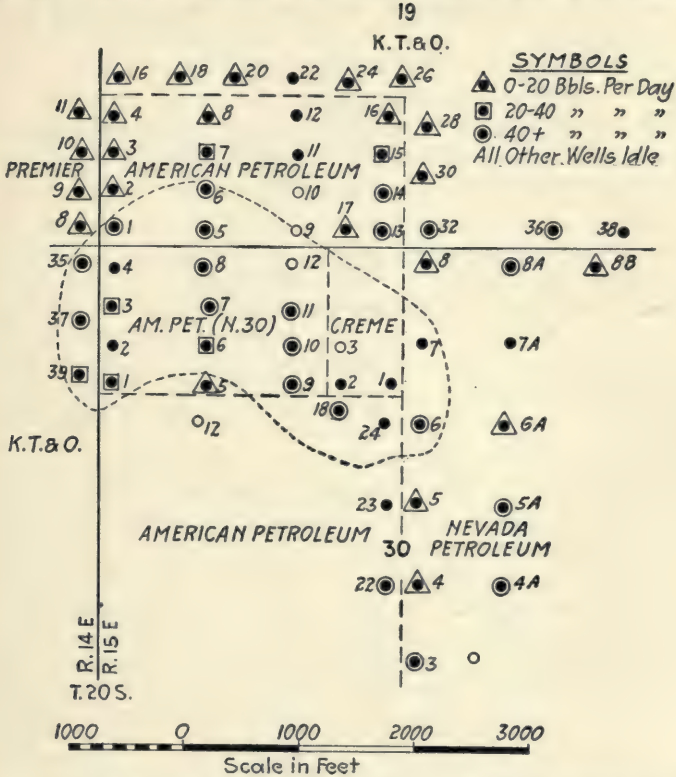


FIG. 32.—Map of portion of Coalinga field showing average amounts of *water* produced daily by various wells in December, 1916.

Of these five wells, two [Creme Petroleum No. 1 and American Petroleum No. 2 (N-30)] entered water below the oil sands; both wells were plugged in an attempt to shut off this water from the oil sands. It appears that the plugging in Creme Petroleum Well No. 1 was successfully demonstrated. No evidence has been presented to prove that the plugging in American Petroleum Well No. 2 (N-30) was successful.

"The foregoing statements show that there is not yet enough evidence to justify an order for extensive repair work on any individual well. They also show that further tests and investigations are justified for the purpose of more definitely locating the source or sources of water at present entering the oil sands, and then repairing the well or wells causing the damage."

It was ordered that the following tests be made:

"Two comparatively inexpensive tests can be made on certain wells, namely, tests to determine depths at which fluid stands in each well, and tests to more frequently and accurately measure the amounts of oil and of water produced by each well. The wells requiring these further tests are:

Kern Trading & Oil Co........	Nos. 35, 37. 39.	Sec. 25, T. 20 S., R. 14 E.
American Petroleum Co........	Nos. 1, 5, 6.	Sec. 19, T. 20 S., R. 15 E.
American Petroleum Co........	Nos. 1 (N-30), 3 (N-30), 6 (N-30), 7 (N-30), 8 (N-30), 9 (N-30), 10 (N-30), 11 (N-30)	Sec. 30, T. 20 S., R. 15 E.
American Petroleum Co........	Nos. 18, 24	Sec. 30, T. 20 S., R. 15 E.
Nevada Petroleum Co.........	No. 6	Sec. 30, T. 20 S., R. 15 E.

"The test to determine the depth at which fluid stands is to be made by withdrawing the tubing from the well, and, after 10 hours from the time the tubing is removed, measuring to the surface of the fluid. This test must be made at each well within sixty days.

"The measurement of amounts of oil and of water produced is to be made by running all fluid from the well into a tank of not less than fifty barrels capacity; the flow into the tank to continue for 24 hours, unless sufficient to fill the tank in less time. At the end of the prescribed period of time the flow into the tank shall be stopped, and the total fluid measured. Such free water as may have settled to the bottom of the tank is to be drawn off and the remaining fluid again measured and sampled to determine the amount of water held in suspension, as shown by proper test with centrifuge.

"The measurements of amounts of oil and of water must be made at each well at least once a week during the sixty days following the date of this order. A written statement covering all these tests to be filed at the end of sixty days."

The various tests and measurements previously specified in the order were completed as follows:

"The depth to the top of the fluid in the various wells was determined

as specified. The amounts of oil and water pumped from the various wells were determined as specified.

"A model was constructed, and samples of the water, pumped from the various wells, were collected and analyzed.

"The depth of fluid in Creme Petroleum Well No. 1 was also determined.

"Comparison of all these data indicate that the damage complained of as originating in Creme Petroleum Well No. 1 affects only a portion of the wells previously enumerated in the order. The wells within the zone probably affected by the condition of Creme Petroleum Well No. 1, are as follows, all in Section 30, T. 20 S., R. 15 E., M. D. B. & M.

American Petroleum No. 9 (N30)	American Petroleum No. 24
American Petroleum No. 10 (N30)	Nevada Petroleum No. 6
American Petroleum No. 11 (N30)	Nevada Petroleum No. 7
American Petroleum No. 12 (N30)	Creme Petroleum No. 1
American Petroleum No. 18	Creme Petroleum No. 2

"The result of pumping tests, fluid level measurements and water analyses is as follows:

	Bbl. oil per day	Bbl. water per day	Depth of fluid level	Analysis of water[1]
Am. Pet. No. 9 (N30)	5.0	497.0	1507	Top
Am. Pet. No. 10 (N30)	46.6	17.4	2130	No sample
Am. Pet. No. 11 (N30)	21.0	247.0	1510	Top
Am. Pet. No. 12 (N30)	....	.....	....	No sample, abandoned
Am. Pet. No. 18......	5.3	315.0	1378	Top
Am. Pet. No. 24......	67.0	124.0	1232	Top
Nev. Pet. No. 6......	9.3	326.0	1295	Top
Nev. Pet. No. 7......	....	.....	....	No sample
Creme Pet. No. 1......	....	.....	350	No sample, idle

[1] Comparison of Chemical Content of Waters in this Locality (grains per gallon)

	"Top" Water	"Bottom" Water
Carbonates..................................	6 to 90	90 to 190
Chlorides..................................	20 to 50	150 to 390
Sulphates..................................	30 to 200	0 to 4
Total solids..............................	115 to 260	370 to 550

"The highest fluid level is in Creme Well No. 1; the next highest fluid level is in the adjoining well, American Petroleum No. 24; and the fluid levels are lower as the distance from these wells is increased in any direction. When American Well No. 24 was measured for fluid level no free water was found in the bottom of the well, and the first pumping test produced almost no water, which indicated that it was not the source of the damaging water in surrounding wells.

"Nevada Petroleum Well No. 7 is at present being repaired and has a plug between the oil sand and top water in such condition as to indicate that it is not flooding surrounding wells.

"American Petroleum No. 11 (N30), while having a high fluid level, is separated from the other wells by a well having a low fluid level. The first showing of water in the well was gradual, indicating that it was not the source of the water. It may, in the future, require testing, but not until more probable sources of water have been eliminated.

"The wells within the group herein mentioned showed marked increase of water in the following chronological order:

Creme Petroleum........................	No. 1	July, 1912
Nevada Petroleum........................	No. 6	Nov., 1912
American Petroleum........................	No. 18	Jan., 1913
American Petroleum........................	No. 24	Jan., 1913
Nevada Petroleum........................	No. 7	April, 1913
American Petroleum........................	No. 9 (N30)	June, 1913
American Petroleum........................	No. 11 (N30)	March, 1914
American Petroleum........................	No. 10 (N30)	July, 1914

It was ordered, that work be performed on Creme Petroleum Well No. 1, in accordance with either of the two methods specified as follows:

"*First:* Redrill or open the well to a depth of 2425 ft., put in a shot between depths of 2415 ft. and 2425 ft., consisting of at least 75 pounds and not more than 250 pounds of 80 per cent. gelatin; again clean out well to a depth of 2425 ft., and, if deemed necessary by the Supervisor upon inspection of the work, and upon his so ordering another shot of similar size and material must be put in at the same place; then wash out hole by means of clear water, place cement plug between depths of 2425 ft. and 2415 ft.; determine

to the satisfaction of the Supervisor that said cement plug has properly set; put in additional cement in the hole sufficient to fill it up to a depth of about 2400 ft.; leave sufficient casing in hole to act as a conductor from the ground surface to a depth of 2400 ft.

"*Second:* Place a string of casing at a depth not greater than 2415 ft.; cement said string of casing, and satisfy the Supervisor that casing prevents the passage of water to points below the bottom of casing."

The well was abandoned according to the first method specified.

A general improvement of neighborhood conditions was reported after the Creme well was abandoned, and no special attention was thereafter given to the problem until some three years later when an accurate gauge was again made at the wells involved.

Comparison of producing conditions before and after the repair work is afforded by the following tabulated statement:

Well No.	April, 1917		February, 1920		Depth to top of fluid, ft.	
	Oil, bbl. per day	Water, bbl. per day	Oil, bbl. per day	Water, bbl. per day	1917	1920
American Petroleum 9.	5.0	497.0	30.0	5.0	1507	
American Petroleum 10.	46.6	17.4	31.0	1.0	2130	
American Petroleum 11.	21.0	247.0	36.0	40.0	1510	1842
American Petroleum 18.	5.3	315.0	26.0	146.0	1378	1607
American Petroleum 24.	67.0	124.0	17.0	134.0	1232	
Nevada Petroleum 6.	9.3	326.0	27.4	44.6	1295	1178
Total.	154.2	1526.4	167.4	370.6		
Average per well per day	25.7	254.0	27.9	61.0		

One of the outstanding features shown by these figures is the very great reduction in the amount of water produced—1526 bbl., as against 370 bbl. per day. Before the repair work was done about 10 bbl. of water accompanied each barrel of oil, while

after the repair the proportion was about 2 bbl. of water to one of oil. The mere reduction in the amount of water probably somewhat reduced the operating expense.

The increase in the amount of oil produced, from 154 bbl. to 167 bbl. daily, does not at first appear to be remarkable, as it is only about 8 per cent. However, three years had elapsed between the two gaugings and the natural decline in production in that locality would probably amount to about 8 bbl. per well per day, judging from results at neighboring wells.

The net result, therefore, was that each well produced about 10 bbl. per day more than it would have produced if there had been no repair. Furthermore, it is not unlikely that, had the water not been excluded, some of the wells would have been entirely flooded and abandoned.

Kern River Field, California

A detailed investigation of a flooded area in the Kern River field was made in 1916, which led to the plugging of two wells. This work more than doubled the output of oil and reduced the daily output of water from 16,000 bbl. to about 250 bbl.

The water had been handled by two air compressor plants, which were not needed after the two wells were plugged. The elimination of expense for fuel and operation, together with the increased output of oil, made the plugging very profitable, and definitely proved the value of scientific investigation.

This instance serves to exemplify the loss following the failure to keep complete records of well conditions, and the consequent wide differences of opinion as to the cause of damage. The report of the investigators summarizes all the available evidence and is therefore quite lengthy. A presentation of the entire report seems justified because it illustrates not only the method adopted in the investigation, but also gives a complete statement of the early operating methods in use before scientific studies had been made of any of the problems.

The wells are located as shown in the accompanying map (Fig. 33)

The State Oil and Gas Supervisor received a letter from the Alma Oil Company, Petroleum Development Company (A. T. &

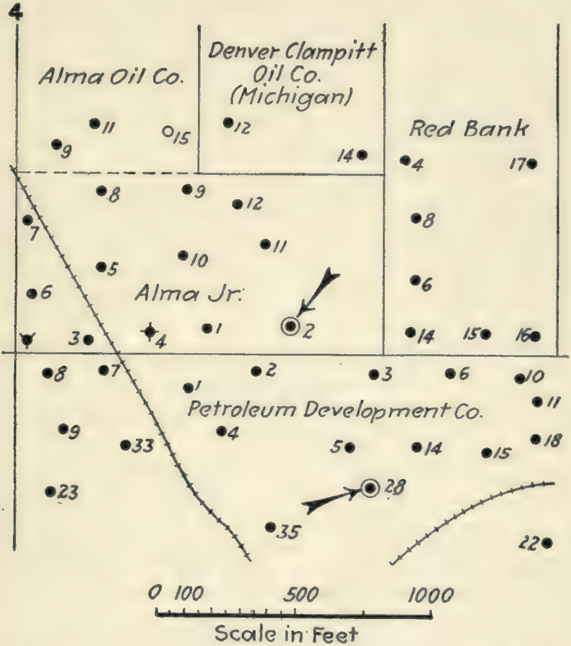


FIG. 33.—Map showing certain wells repaired in Kern River Oil Field, California.

S. F. Ry. Co.), and Associated Oil Company, dated July 11, 1916, reading as follows:

"Water has long been a menace to the properties of the undersigned in sections 4 and 5,-29/28, Kern River Field, and each of us has spent large sums in vain attempts to cure the difficulty.

"We now submit our problem voluntarily to you asking your prompt investigation of the conditions, and your recommendations regarding curative work. Our records are at your disposal, and we request your prompt attention."

The report of the state supervisor, dated Feb. 27, 1917, is as follows:

"The requested investigation was carried on as fast as the necessary records and adequate engineering assistance became available. This report is largely the result of work done by Deputy Supervisor R. N. Ferguson and Inspector G. McGregor.

"The Supervisor expects the recommendations herein contained to be promptly carried forward.

"The damaging conditions complained of seem to have first become acute in the early part of the year 1904.

"The early part of the work of investigation consisted of collecting the logs and other information on which to base an investigation. We have succeeded in getting some sort of a log of every well concerned. Many of these are meaningless; in fact, very few of them furnish complete records of the wells. The other information that we have obtained is even less satisfactory than the logs.

"Mr. Beard of the Alma Oil Company has made a painstaking attempt to secure dates, facts and figures for us, and what we have secured come almost entirely from him. However, he has not yet furnished us any production reports, as required by law.

"The Associated Oil Company has furnished us production reports covering the year just passed, but practically nothing concerning the early production of the district.

"The Petroleum Development Company has furnished us a report of the production of its wells for the month of July, 1916, but absolutely no information as to the history of the water trouble.

"This preliminary statement is made merely to show the difficulties encountered in making the investigation, due to the lack of information furnished. In spite of this handicap we are certain that, when the recommendations made herein are put into effect, conditions will be materially improved. Furthermore, we expect to gain enough information from watching results of the work ordered to enable us later to locate the remaining sources of trouble.

"The conditions of the wells considered in this work are listed in the appended historical sketch in the order of their drilling. The sketch also contains the dates of some other events bearing on the subject.

1900

Sept. 2d to Dec. 2d	P. D. #2	Drilling
Sept. 19th to Nov. 25th	P. D. #3	Drilling
July 20th to Mar. 26th, 1901	P. D. #1	Drilling
Nov. 7th to Jan. 25th, 1901	P. D. #4	Drilling
Nov. 29th to Feb. 4th, 1901	P. D. #5	Drilling
Dec. 30th to Jan. 30th, 1901	R. B. #2	Drilling
Dec. 31st to Mar. 24th, 1901	P. D. #6	Drilling

1901

Feb. 14th to Mar. 9th	R. B. #3	Drilling
Apr. 5th	R. B. #6	Drilling
Apr. 9th to May 8th	A. J. #1	Drilling
Apr. 9th to May 2d	A. J. #2	Drilling
Apr. 29th to May 23d	R. B. #7	Drilling
June 5th to June 25th	R. B. #8	Drilling
June 6th to July 9th	P. D. #7	Drilling
June 14th to July 20th	A. J. #3	Drilling
June 15th to July 13th	A. J. #4	Drilling
July 10th	P. D. #8	Drilling
July 30th to Sept. 13th	A. J. #5	Drilling

Alma Jr. Co. wells averaged 1250 bbls. per month each, and showed no water, according to W. W. Stephenson's letter.

1902

Sept. 9th to Oct. 4th	P. D. #10	Drilling
Sept. 18th to Oct. 29th	P. D. #11	Drilling
Oct. 6th to Oct. 29th	P. D. #12	Drilling
Oct. 25th to Dec. 27th	P. D. #13	Drilling
Nov. 2d to Dec. 31st	P. D. #14	Drilling

1903

May 16th Alma Jr. Co. borrowed money to pay for Jack Plant.

May 18th Alma Jr. Co. made first sale of oil.

June 15th Alma Jr. #2 sanded up.

Aug. 20th Alma Jr. #2 pumping.

Aug. 29th Alma Jr. #2 still pumping.

1904

Feb. 21st Red Bank #14 and #15 completed. Water showed in P. D. #6 (see Stephenson's letter).

Early in the year oil from Alma Jr. #2 sold to Santa Fe. R. R. Co.

1905 Reports of E. H. Andrews of the P. D. Co. on progress of repair work on Alma Jr. #2.

Apr. 2d Alma Jr. #2 plugged with cement up to 690′.

Rasmussen #12 increased the production of oil since the above work. When shut down was pumping pure water.

April 9th Alma Jr. #2, 7⅝″ casing parted.

Reported result of dye test showing that water still spreads to other wells from Alma Jr. #2.

April 16th Alma Jr. #2 pulled all 7⅝″ casing, put another ton of cement in bottom. Cement all washed away as fast as put in.

April 23rd Alma Jr. #2, 9⅝″ casing cut and swedged at 350′ to plug for top water.

May 7th Alma Jr. #2 plugged for top water at 350′, Top and bottom plugs appear to be tight. Cement in bottom set hard. Scow brings up dye coloring that has been in the well four days.

Extracts from Letters (Stephenson to Beard).

May 12th Alma Jr. Co., and P. D. Co., endeavored to get the A. O. Co. to test shut-off in Red Bank #14.

May 18th P. D. Co. convinced water troubles not due to Alma Jr. #2.

June 19th P. D. Co. Rasmussen Lease, shipped 32,000 bbl. more oil during October than during the previous month.

Nov. 19th Alma Jr. #2 pumps about all water unless stopped for a while, when it fills with oil.

Nov. 19th P. D. #1 and #2 have begun to produce oil instead of water, but #6 opposite Red Bank still produces all water.

1906

July 1st Alma Jr. #1 showing water again.

July 1st P. D. #7 shows water for the first time. P. D. #3 and #4 show no water.

July 30th Alma Jr. wells improving in production. P. D. Co. wells pumping straight water.

Dec. 13th Alma Jr. wells, excepting #5, producing water. P. D. Co. wells steadily producing water.

1908	Oct. 16th	P. D. Co. #30	Completed
	Nov. 25th	P. D. Co. #31	Completed
	Dec. 31st	P. D. Co. #32	Completed
1908–1910		P. D. Co. #28	Drilling

"Letter dated July 25, 1916, from W. W. Stephenson to Deputy Supervisor Chester Naramore, reads as follows:

'The Alma Jr. Company drilled its first five wells along the south line of their property during the year 1901, and they were all finished at about 800 ft. stopping in the oil sand as the logs will indicate.

'At this time the Petroleum Development Company had six wells producing just south of them which were all good producers with the exception of their No. 3 well which never produced much.

'Alma Jr. operated these wells from a Jack in conjunction with the Alma Company, and each well produced from 1,100 to 1,500 bbl. per month and showed no water, and gave no trouble.

'The first water appeared while the Associated Oil Company was drilling Red Bank No. 14 situated in the S. W. corner of their property, and showed first in P. D. No. 6 well, but as the A. O. Co. were losing considerable water in drilling that well, no special attention was paid to it, as it only appeared in the P. D. No. 6 which was located just across the line, and this was expected so long as drilling was going on in the R. B. well, although its production all went to water during the drilling of the R. B. well, and gave considerable trouble to keep going.

'Upon the completion of the drilling of the R. B. No. 14 it was expected that water would soon disappear, but after waiting for a reasonable length of time, long enough so that all lost water should have been exhausted, and the P. D. No. 6 as well as R. B. No. 14 both continued to pump water, the former all water, and the latter with only a showing of oil after perforation, it caused considerable alarm.

'After pumping this way for several months, the water appeared in P. D. No. 11 which is behind the hill from No. 6, then in P. D. No. 3 located west of No. 6, and remained so for about a year, when it again started to spread and reached P. D. No. 2, which well had been the best producer that company had, and the loss was felt by them very greatly.

'During all this time none of the wells of the Alma Jr. had shown any water, but within about four months after water broke into P. D. No. 2, it started to show in Alma Jr. No. 2 located just north of P. D. No. 2 and in a short time this well was all water, and had been from that time on showing no oil to speak of, but seemed to become a fountain head of water that was inexhaustible.

'Alma Jr. No. 4 was next to show water, situated in the canyon to the west of the others; this, however, after about all the other P. D. wells were pumping water, as the flow seemed to start at P. D. No. 6 and worked S. E. first, then spread south and drifted along west which at that time was the territory that was developed, and then slowly worked

north again in the Alma Jr. wells in the canyon, first striking No. 4 and for some time Alma Jr. wells Nos. 2 and 4 were only effected,—the others still producing oil in large quantities, while about all of the wells of the P. D. Company at that time were producing water, although Alma Jr. No. 1 and No. 3 are situated between wells Nos. 2 and 4 along the south line of the Alma Jr. property, showing that for some reason the water traveled around these two wells to reach Alma Jr. No. 3 and No. 2, and this continued along for about two years after water broke into the field even though No. 1 and No. 5 were the two best wells the Alma Jr. had and all during this time were producing heavily.

'About this time, which was some years after the drilling of these wells, attempts were made to try to trace its origin through the use of colors put into the different wells while pumping, and considerable time was spent in this, and the results were closely watched, and the tests so made would indicate that Alma Jr. No. 2 well seemed to be a distributing head to all of the wells, as colors placed into this well would be pumped out from all of the surrounding wells, while colors placed into any of the other wells were not so certain. This led the officials of the P. D. Company as well as the A. O. Company to think this well the source of water supply, and while the writer was unable to explain why it was not, it seemed impossible to me that this well should continue to pump oil for two years after the water broke in before it started making water. If it was the fountain head and source of the supply, it would certainly have shown sooner in the well, but in a spirit of fairness to the others, I consented that work should be done on the well, knowing quite well it would not remedy the trouble, but feeling that something must be done at once as water was slowly backing into our property, and it would only be a short time until it was flooded out. Therefore, arrangements were made between the three companies interested and H. B. Guthrie, who at that time was introducing a method of his own for shutting off water, to take charge of the well and power to do anything he thought necessary to stop the flow of water, he at that time guaranteeing to shut off the water. His process was the tamping of sand with a line casing. However, after working for a long time on the well without results he decided it was not this well that was making the water, and he started on R. B. No. 14 but worked only a short time when work there was also discontinued.

'The P. D. Company then took over the well, not being satisfied that the work was properly done by Guthrie, and after spending a lot of

money and time, also discontinued the work, which was a loss, and no benefit was derived from it, either in the way of stopping the water or learning its source.

'It is quite apparent to my mind that the water comes from some other well, which one I am not prepared to say, but I think it should be looked for either in Well No. 14 R. B. or in No. 6 P. D., as those two wells were pumping water for a long time before any of the others showed any signs. However, it is quite clear that the water travels to Alma Jr. No. 2 in a general body, from which point it is distributed to all wells located south of it, and now even north of that point, as is shown by its entering into Alma Jr. No. 12.

'From the fact that all early water was shut off at the 320 foot level while drilling the major portion of these early wells, and oil sand was entered into at that point, most of the casing below that point is perforated, whether shown on the logs or not.

'Alma Jr. No. 7 was drilled into a heavy fluid and we were never able to pump it with any success, whether this was chilled by the water or not I was never sure. I think, however, that it would always have been a very heavy oil, as the sand taken out would indicate a heavy tar formation. This well was abandoned on this account; and while I do not remember the amount of casing that was withdrawn, it was a very small amount, and did not touch any water string."

"The conclusions drawn herein have been reached after a careful study of the foregoing history and the accompanying cross-sections. Three cross-sections have been drawn, as follows:

No. 1. East and West through the North line of wells on the Petroleum Development Company property.

No. 2. East and West through the South line of wells of the Alma Jr. and Red Bank properties. (Fig. 34.)

No. 3. North and South through the wells along the West line of the Red Bank property, extending South into the Petroleum Development property.

"That these cross-sections do not more decisively portray the geological structure, is due almost entirely to poor records. By making use of information previously published by the State Mining Bureau on the Kern River Field, it has been possible to make correlations that are as nearly accurate as is necessary for the purpose of this investigation.

"A study of the cross-sections shows the existence of two practically continuous clay strata about 150 ft. apart. Had either of these been

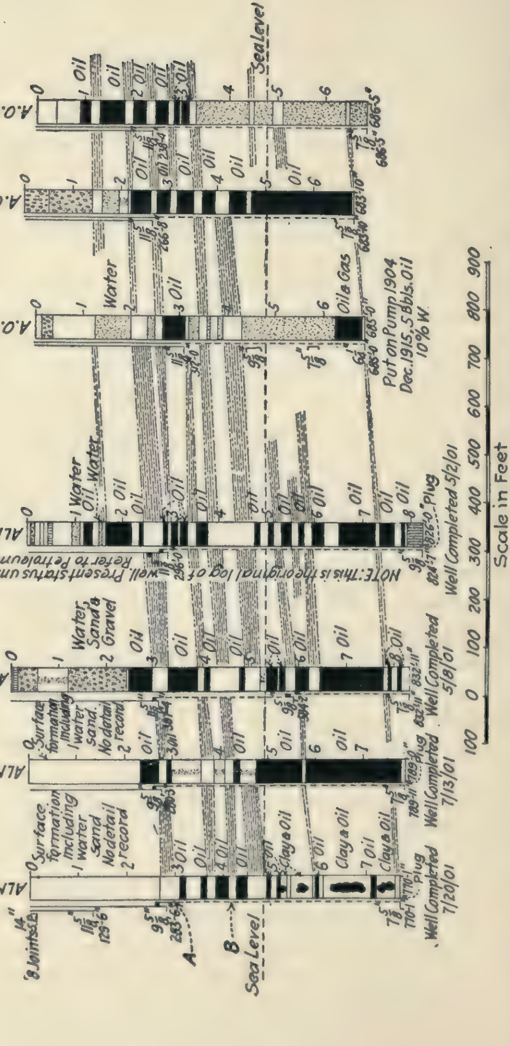


FIG. 34.—Cross-section showing certain wells in Kern River Oil Field, California. (The figures at the right hand side of each well represent depths in hundreds of feet.)

used as a landing place for water strings by all the wells in the district, top water troubles would never have been known. The upper one is marked A on the prints; and the lower one B. The upper one is below the lowest top water logged in any of the wells, and many of the wells have their water strings landed in it.

"In cross-section No. 2 it will be noticed that Alma Jr. Nos. 1, 3 and 4 are landed in this clay stratum, while Alma Jr. No. 2 and Red Bank Nos. 15 and 16 are a trifle below it, but in all probability not enough deeper to cause the flooding of the producing sands of the former group. It will also be noticed that the point of shut-off in Red Bank No. 14 is at least 50 ft. below this clay, and below the first producing oil sand of all the other wells. This fact certainly lends color to the above expressed belief of Mr. W. W. Stephenson that Red Bank No. 14 is flooding the producing sands of the other wells.

"In cross-section No. 3, 14 wells are shown, of which three have their water strings landed in the upper clay stratum. They are the Petroleum Development wells Nos. 30, 31 and 32. Red Bank Nos. 9, 10, 11 and 13 are shut off in the lower clay B; Red Bank No. 14 and Petroleum Development Nos. 14 and 28, in the same relative position, about half way between A and B; Red Bank Nos. 7 and 4 respectively 50 and 200 ft. below B; Red Bank Nos. 6 and 8, 50 ft. above A.

"In cross-section No. 1 the Petroleum Development Company wells Nos. 10, 12 and 13 are shown to be shut off between A and B. No casing records of the other six wells have been furnished. We have Mr. Stephenson's statement to the effect that all but No. 3 were good producers until 1904, and the presumption is that there is some uniformity to their points of shut-off.

"Thus it will be seen that if the troubles in this vicinity are due to top water, a large and costly piece of work will have to be done to correct them. How this is to be handled is a matter for later consideration.

"In the matter of bottom water, the cross-sections indicate two wells that are likely to be offenders. These are Petroleum Development Company No. 28, which has both oil and bottom water cased off behind the same pipe, and Alma Jr. No. 2, which is deeper in the formation than any surrounding well except Petroleum Development No. 28.

"At present Petroleum Development No. 28 is undoubtedly flooding the oil sands, but as it was not drilled until 1908 it clearly is not the first offender.

"From the foregoing historical sketch it can be seen that the Petro-

leum Development Company's North line wells were drilled in the years 1900 and 1901 and as far as we can ascertain produced satisfactorily and gave little or no trouble.

"In the years 1901 and 1902 the Alma Jr. Oil Company completed their first five wells which, according to Mr. W. W. Stephenson, produced 1250 bbl. more or less of oil per month, showed no water and gave no trouble. Although Mr. Stephenson does not directly state it as a fact, he intimates very strongly that the wells were pumped on a jack as soon as they were brought in, while as a matter of fact the wells were not pumped until the spring of 1903, so that Mr. Stephenson's statement that the wells "showed no water and gave no trouble" is refuted by several men now in the Kern River Field who claim that Alma Jr. No. 2 was a "wet one" from the first.

"According to Mr. Stephenson water first showed in this portion of the field while the Associated Oil Company was drilling its Red Bank No. 14 well, and gradually became worse. Finally in the spring of 1905 the representatives of the three companies concerned met and decided that something must be done to remedy the trouble, and a man was employed to work on Alma Jr. No. 2. After working for some time in vain, he abandoned the attempt, saying he did not think that well was making the water. He next went to work on Red Bank No. 14, but was equally unsuccessful in effecting a cure for the trouble. (See Stephenson's letter to Naramore quoted above).

"Mr. E. H. Andrews of the Petroleum Development Company had some theories of his own in regard to shutting off water, so permission was obtained from the Alma Jr. people to allow him to do some work on the well. What work he actually did, it has been impossible to determine due to lack of complete records, but copies of a few scattering reports indicate that he attempted to plug the well both for top and bottom water. We are informed that he dumped wagon loads of old pump-barrels, etc., into the hole, and upon introducing the tools, no trace of them was found, showing that an enormous cavity must have existed there.

"We are also informed that during the course of his work, he loosened the water string, but whether he was able to repair the damage caused by this operation or not we have been unable to learn. The data we have on the subject would indicate that the string was loosened and raised about 20 ft., where it froze and was left.

"After much discussion it was agreed to try a "dye test" to determine

the source of supply. The dye was put in several wells, including Red Bank No. 14 and Alma Jr. No. 2. In each case the dye was introduced through tubing from the surface to the fluid level inside the oil string. No satisfactory results were obtained until the dye was put in the Alma Jr. No. 2, when it spread rapidly throughout the district, the first wells showing the color in about 20 minutes from the time it was placed in the Alma Jr. well. This would indicate that this well (Alma Jr. No. 2) was a distributing head for other wells in this vicinity.

"This theory is supported by the fact that at the conclusion of Mr. Andrew's work on the well the production of neighboring wells showed a marked improvement, and extracts from Mr. Stephenson's letters to Mr. Beard indicate the optimism of the whole district. Under date of June 20, 1905, he states:

'The Alma Jr. wells are going to be as good as they ever were if the water keeps on as it is now, as the Petroleum Development wells are all going back to oil again, and they are now getting seventy-five barrels a day out of No. 1; and No. 2 is pumping about half oil and throwing a big stream all the time, and they are going to put in a six-inch pump, and an eight-inch drive-pipe in No. 6, and then I look for all of these wells at this end to do oil as that will exhaust the water up there.'

"Again under date of November 19, 1905, he writes to Mr. Beard: 'I have your letter of the 17th, and am surprised that you did not get my letter telling about the water situation, but will say it is coming along in good shape, and each day since I wrote you it has continued to improve. Up until last month the Petroleum Development Company was not getting over enough oil from Rasmussen Lease to burn for fuel, and during the month of October they shipped out 32,000 bbl. and are shipping this month more than ever and gaining in storage.

'There are only three wells that pump water, so to speak, and the rest are pumping the same as they originally did, and the water is centering around Red Bank No. 14 well, but the Alma Jr. No. 2 pumps about all water unless it stops for a while, then it will fill up with oil at once, but when pumped down, it pumps oil and water mixed; but wells are coming back all of the time and two more came back to oil again yesterday, Nos. 1 and 12, which were two of the worst; but No. 6 opposite No. 14 is all water.'

"This condition continued until some time in the spring of 1906, when water commenced to get the better of them again, and it has practically held down the production of oil ever since.

"Assuming Alma Jr. No. 2 to be one of the guilty wells, (and it is proven beyond a doubt that it is at least a distributing head), the above stated condition would seem to indicate that the work done by Mr. Andrews had a beneficial effect, if only temporary; and seems to point toward the conclusion that more thorough and judicious work at that time would have had more lasting effects.

"In one report dated April 16, 1905, Mr. Andrews states:

'Got out all of the 7⅝-in. casing and put in another ton of cement in bottom. Cement all washed away as fast as put in. Getting ready to pack for top water.'

"From this statement, and from the amount of junk he is said to have thrown into the well without obtaining a trace of it afterward, it would seem that the well was not only a distributing head, but was itself making bottom water, and the results would indicate that it was not plugged off.

"A further indication that the well was drilled into bottom water may be deduced from the experience of the E. A. Clampitt Oil Company, situated a quarter of a mile north of Alma Jr. This company drilled a well into bottom water at a depth of approximately 807 ft. The surface elevation of the Clampitt is from 60 to 75 ft. above that of the Alma Jr. No. 2. Allowing for the difference of elevation of the two wells together with the dip of the strata, Alma Jr. No. 2 would be a little shallower than the Clampitt well; while as a matter of fact it is 826 ft. deep. The log of the well shows a sandy shell for the last 35 ft., and the cross-section shows that this well is deeper in the formation than any of its neighbors so there is very little doubt in our minds that this well encountered bottom water when drilled.

Conclusion.—"The following recommendations are made with the idea that the first work done will correct the most obvious sources of trouble, and thus, by elimination, enable us to determine the remaining sources of the trouble.

"As the matter now stands it is certain that both top and bottom water have access to the producing oil sands. To repair the wells that are making bottom water is a simple matter compared to correcting the top water troubles. We therefore recommend that the bottom water conditions in Alma Jr. No. 2 and Petroleum Development Company No. 28 be corrected first.

"To enable us to make a test on the plugging for bottom water it will, of course, be necessary to have top water shut off. To this

end the Alma Jr. Company should immediately pull the oil string in Well No. 2, bridge below the point of shut-off, and bail the well for a test. They should then redrill to original bottom, driving any old casing into the walls, and plug with cement up to 725 ft. When this cement is set, a pumping test will be necessary to determine whether or not the well still makes water. In the event that it still makes the same amount as heretofore, it will indicate that the water is being let in through the oil sands by low shut-offs of surrounding wells, and it should be allowed to stand until the latter condition is remedied.

"Petroleum Development Well No. 28 should be abandoned and plugged, unless this has already been done and not reported. A solid plug put into the walls of the hole at a depth of 760 ft. would protect the producing oil sands reported in surrounding wells. If the log of Petroleum Development Well No. 28 is accurate in reporting oil sands to the depth of 900 ft., nothing less than a solid plug against the walls of the hole from 900 up to 760 ft. would be satifsactory. This work alone should materially improve conditions. How much of the trouble it will overcome is uncertain. It is very likely that it will eventually be necessary to establish new points of shut-off in about half of the wells in the district before an absolutely clean production of oil can be secured.

"Among the wells most in need of such repair are Petroleum Development Company Wells Nos. 3, 10, 13, 14 and 28., Red Bank Nos. 4, 6, 7, 8, 9, 10, 11, 13 and 14. The magnitude of such a program of repair work indicates what an undertaking it would be to establish uniform shut-offs in the district, and brings up the question of the method to be used.

"Common practice would demand redrilling every well to be repaired, but it seems probable that some simpler and cheaper method could be devised which would enable the operators to re-establish points of shut-off.

"Should the result of the work recommended on Alma Jr. No. 2 and Petroleum Development Company Well No. 28 indicate that the lack of uniformity of points of shut-off is responsible for the water conditions, shut-offs should be established in Red Bank No. 14 and Petroleum Development No. 14, in conformity with those of the Alma Jr. wells."

Results.—Work was carried on at the two wells as recommended. The work on Well No. 28 of the Petroleum Development Company consisted of plugging off the deep-flowing salt

water, well below the lowest oil measures. The work on this well was then suspended, as it was though that a better test could be made of the success of plugging after the work on Alma Jr. No. 2 was completed, than when the sands were being flooded from that well.

Work was begun on the Alma Jr. No. 2 well, February 25, 1917, at which time the 3 in. air line was pulled and an unsuccessful attempt was made to loosen the 7⅝ in. casing. A cement plug was found in the bottom of the 7⅝ in. casing at 874 ft. The 7⅝ in. casing was finally loosened with two 60-ton jacks, and after raising it 20 ft., the cement in the bottom was drilled out.

An attempt was made to plug the well as the 7⅝ in. casing was withdrawn, but it was not successful because every movement of the casing caused the well to fill with sand through the perforations. The 7⅝ in. casing was pulled, the perforated joints replaced with unperforated joints, and the casing run back into the well. As running sand had to be contended with all the way down, the work was slow, and finally, when the casing was down to about 830 ft., the string of tools was stuck in the hole by caving sand. Two weeks time was spent in fishing for the tools, which were finally recovered on April 30, 1917. After several days' work it was found to be impracticable to mud the hole while the sand was heaving in, so the 7⅝ in. casing was pulled out and run back into the hole to a depth of about 702 ft., and thorough mudding of the well was commenced.

The mode of operation adopted was to keep the tools swinging at or near the shoe of the casing, shovel in dry clay and allow a stream of water to run into the well. In this way it was hoped to mud the sands sufficiently so that the casing could be lowered without danger of freezing. By this method the casing was carried down to 789 ft., where it froze after about 1000 cu. yds. of clay had been put in. The hole was then drilled ahead to 886½ ft., using approximately another 100 cu. yds. of clay, and the process of plugging was begun. The hole was plugged solid from 886½ ft. to 826 ft. with clay, cobbles and manila rope. At this depth

the well was shot with 30 lbs. of 60 per cent. dynamite the hole was cleaned out and 15 sacks of cement put in through tubing. A second shot was placed at 792 ft. (32 lbs. of 60 per cent. dynamite) and, after cleaning out to 801 ft., eight sacks of cement were put in through tubing. A third shot was put in from 767 ft. to 773 (50 lbs. of 40 per cent. dynamite), and the hole was cleaned out to 782 ft. Eleven sacks of cement were put in at this depth through tubing. A fourth shot (50 lbs. of 60 per cent. dynamite) was put in from 757 ft. to 765 ft. The hole was cleaned out to 765 ft. and filled with clay and cobbles to 755 ft., and a fifth shot put in from 745 ft. to 752 ft. (50 lbs. of 60 per cent dynamite). The hole was then cleaned out to 755 ft. and tamped solid with clay and cobbles up to 735 ft. A shell containing 50 lbs. of 60 per cent. dynamite was then set on top of the plug and exploded. Following this operation the hole was cleaned out to 735 ft., and after running water in for several hours 13 sacks of cement were put in through tubing. This cement filled the hole to about 722 ft. The hole was then filled up with cobbles, a heaving plug set at 702 ft., and the pipe perforated from 684 ft. to 702 ft.

The inaccuracy of the original records is shown by the fact that the well was found to be some 60 ft. deeper than reported.

Within a week after mud was started into the well it began to show in the fluid pumped from surrounding wells as much as a quarter of a mile away, both up and down the dip of the formation. As soon as neighboring wells showed mud pumping was discontinued, so that the clay would not be unnecessarily drawn away from the well under repair.

About 1140 cu. yds. of clay were used in addition to several wagon loads of cobblestones and other materials. The work extended over a period of six and one-half months. The total cost was about $8,000, of which $4,400 was for labor and $2,500 for hauling clay.

A comparison of the condition of wells in the locality, both before and shortly after repair work, is shown by the following statement of production:

	Daily production before repairs		Daily production after repairs	
	Oil (barrels)	Water (barrels)	Oil (barrels)	Water (barrels)
Alma Jr.—				
No. 1	Trace	150		00
No. 2	00	12,000	Trace	100
No. 5	Trace	200	10	Trace
No. 11	Trace	250	7	40
No. 12	Trace	200	10	25
Pet. Dev. (Santa Fe)—				
No. 1	3	32	4	10
No. 2	00	1,440	*	*
No. 6	5	250	4	20
No. 10	5	400	5	10
No. 14	5	5	5	10
No. 18	7	1,000	7	25
Totals	25	15,927	59	240

* Not yet rigged for pumping.

The effect of the repair work was permanent. After about three years had elapsed, the group of wells was producing 50 bbl. of oil and 60 bbl. of water per day.

Example of Efficient Development of a New Field

The practical value of scientific investigation and control is not limited to the repair of old properties. It is, indeed, of much greater value in the development of a new property.

After these two descriptions of repairing damaged properties it is interesting to follow the detailed description of a new and highly productive field where development work has been planned and executed so as to avoid water damage.

In describing the successful results of the supervisory work of M. J. Kirwan and Irving V. Augur, in the Montebello Oil Field,[1]

[1] Report on Underground Structure of the Montebello Oil Field, Los Angeles County, California, with Particular Reference to Location of Water-bearing Strata. Irving V. Augur, Fifth Annual Report, State Oil and Gas Supervisor, California State Mining Bureau, Vol. V, No. 11 (May, 1920), pp. 6–25.

the latter exemplifies the use of many principles which have been briefly stated in preceding chapters. The report is, therefore, reproduced with but slight modification.

REPORT ON UNDERGROUND STRUCTURE OF THE MONTEBELLO OIL FIELD, LOS ANGELES COUNTY, CALIFORNIA, WITH PARTICULAR REFERENCE TO LOCATION OF WATER-BEARING FORMATIONS

By Irving V. Augur, Deputy State Oil and Gas Supervisor
April 30, 1920

Preliminary Statement

The Montebello field occupies the crest and flanks of an anticline in the La Merced Hills, which lie about one mile north of the town of Montebello and about five miles east of Los Angeles. Topographically the La Merced Hills form a spur at the eastern extremity of the Repetto Hills, which extend westward to Los Angeles and disappear eastward under the Rio Hondo and San Gabriel rivers. The axis of the anticline follows in a general way the east and west trend of the hills, which terminate in rather an abrupt slope at the east end and slope more gently toward the west, where they merge with the valley floor.

The discovery of the field was due to scientific geological study. The first well (No. "Baldwin" 1 of the Standard Oil Company) was started on December 12, 1916, and was completed on February 24, 1917, and the production of the field now amounts to approximately 1,000,000 bbl. of oil per month, or almost one-eighth of the entire production of the state.

The area covered by this report embraces all of the La Merced Hills, which lie north of the town of Montebello, together with the adjacent slopes of these hills, and includes sections 1 and 2, T. 2 S., R. 12 W., section 31, T. 1 S., R. 11 W., and section 6, T. 2 S., R. 11 W., S. B. B. and M.

Surface Geology

No attempt has been made by the writer to map the surface geology of this field in detail, since the correlation of oil sands is so evident, making details unnecessary. The major structure, however, was outlined at the time the field first started, at which time, also, a peg model was constructed, which has been revised as developments have taken place.

The sub-surface anticline of the La Merced Hills conforms very closely to the topography of the hills. The direction of the anticline is nearly east and west with the west end fanning out and possibly turning toward the southwest, while the eastern end plunges away under the Rio Hondo and San Gabriel rivers at a gradually increasing angle, developing into a steep plunge. The highest point in the hills is not, however, the apex of the anticline, which is near the eastern edge of the hills on the Temple Lease of the Standard Oil Company.

Pleistocene gravels flank the hills on all sides, lapping unconformably upon the Fernando formation, which is exposed in the center and the east end of the range. The Pleistocene is characterized by low dips showing recent uplift.

Since the deposition of the Pleistocene, minor faulting has occurred on the south side and east end of the hills, giving dips of 50 to 60 degrees in Fernando shales, which are faulted against shallow dipping Pleistocene sand and gravels. This feature was at first thought to limit the productivity of the anticline on the south side, but subsequent developments indicate that the surface faulting does not extend to the oil measures, which show uniform and gradual dips on both north and south flanks.

Fernando Formations

Eliminating the surface gravels, the wells in this field penetrate about 1500 ft. of shales and sandy shales, showing greyish brown in outcrop and logged by drillers as blue shale. Beneath this series are strata of hard conglomerate or gravel from 50 to 200 ft. in thickness. Beneath this bed of conglomerate lie

strata of brown shale or sandy shale with occasional beds of sandstone. This formation is approximately 200 ft. thick and forms the cap beneath which lie the oil formations. The productive formations consist of sands separated by several hundred feet of brown shale or sandy shale similar in character to the shale immediately below the conglomerate.

The formations above the conglomerate are undoubtedly of Fernando age. The oil formations lying below the conglomerate are classified by some geologists as Fernando, by others Puente and by still others as uppermost Monterey. This lack of agreement as to the exact age and distinction of formations penetrated is due to scarcity of fossils discovered at depth and to a general misunderstanding as to the exact definition of the above mentioned terms, which definition has never been thoroughly established. The age of the formations encountered in drilling is interesting only from a scientific standpoint and in its application to newly discovered fields in determining the possibilities of production from lower horizons.

Underground Structure and how Determined

For the purpose of correlating formations penetrated, various ideas were at first used, such as base of conglomerate, top of brown shale as logged, and first oil showings as reported. Correlation based on any one of the above methods was found to be roughly satisfactory, but was not in many instances accurate enough to determine the location of water sands, which later appeared in the oil measures themselves and which began to give trouble.

As a result of a further study by the writer, therefore, a new basis of correlation was established, which correlation seems to give better satisfaction than any method previously used. The indicator used in this method is the first main oil sand. With the exception of a shallower lenticular sand in the western portion of the field and a still higher (stratigraphically) lenticular sand near the apex of the fold the oil sand used for an indicator is the first oil sand below the shoe of the water string.

The method of drilling in this field previous to the time this correlation was established had been to proceed with drilling until the first showing of oil was noted in the rotary mud, when the well was bridged and the water string cemented. This first showing, with exception of lenticular sands mentioned above, was invariably in shale or sandy shale, so that the first main oil sand, being the first sand to be encountered, was more accurately logged than any of the succeeding sand strata penetrated. For this reason, when once the idea was discovered, the correlation of underground measures in the field progressed rapidly.

On the basis of this correlation, contour maps and sections have been prepared as shown on the following pages. These diagrams show in detail the underground structure of the Montebello field.

Reference to diagram of ideal graphic log and ideal cross sections indicates the following grouping of formations into zones as now used.

First or Upper Oil Zone.—This designation has been given to the upper producing series of strata in this field limited by the basal conglomerate zone above and by the intermediate edgewater beneath. In the central dome is also included with this zone, for convenience in reference, the portion of the intermediate edgewater sand which carries oil.

This zone is composed of 1000 ft. of grey or brown oil-bearing shales and sandy shales lying just beneath the base of the conglomerate and containing several lenticular oil sands near the top and middle and also the first main oil sand near the base. This formation is capable of producing from 20 to 1000 bbl. of oil per day, depending upon its proximity to the apex of the fold.

One point of particular interest in relation to the productivity of this zone, from a study of wells producing from it, is that, regardless of the nature of the driller's log as to oil showings, no increased production is obtained by drilling the well below the base of the first main oil sand. It is, therefore, unnecessary and not economical to finish a well in this zone deeper than the base of the first main oil sand. Deeper drilling involves the danger

of getting too close to the intermediate edgewater sand and endangering the well from water infiltration.

Intermediate Edgewater.—This name is given to the first persistent water bearing formation encountered below the first main oil sand in this field. The type name is derived from the fact that the lower limit or edge of the oil deposit in an oil sand is generally marked by water *in situ*. The intermediate edgewater sand in this field, except in the central dome, contains only water. The interval between the top of this edgewater sand and the top of the first main oil sand of the first oil zone is about 300 feet. The line of edgewater exists in this stratum at a depth of about 2250 ft. below sea level. The portion of this edgewater sand which contains oil in the central dome is grouped with the first oil zone.

Second Oil Zone.—The classification, as arbitrarily assumed for this zone, includes the productive formations from the base of the intermediate edgewater sand to the top of the lower intermediate water sand.

This oil zone is approximately 1000 ft. thick and the most productive portion is in the lower 500 ft. Production is obtained from grey or brown sandy shale, interstratified with more or less lenticular oil sands, and initial production from this zone has amounted to as much as 15,000 bbl. per day from an individual well.

Lower Intermediate Water.—At the base of the second oil zone, and defining its lower limit in the center of the field, is a second or lower intermediate water formation. This water sand lies at a depth of about 3700 ft. below the surface and from 1450 to 1475 ft. below the indicator (first main oil sand). It has only been encountered in the central dome where the deepest wells (stratigraphically) in the field have been drilled, but may exist throughout the entire field.

Third Oil Zone.—This zone includes all productive formations which have been encountered below the lower intermediate water sand to date and any additional productive formations which may be encountered by deeper drilling, the lower limit

to be defined by additional and deeper (stratigraphically) water formation, if such a formation is encountered.

Only about 300 ft. of this zone has been penetrated to date, but this much of the zone has produced 1500 bbl. of oil per day, with water from the lower intermediate water sand not excluded. The formation consists principally of hard grey sand.

Basal Conglomerate Zone.—This name is given to designate a certain zone variously logged by rotary drillers as hard sand gravel, conglomerate or shale and boulders, and lying immediately above the brown shale which acts as a capping for the first oil zone.

Central Dome.—This phrase has been used to describe that portion of the center of the field constituting the apex of the anticline under which the intermediate edgewater formation carries oil instead of water.

The foregoing subdivision of productive formations embraces the underground structure as it appears at present. The drilling of new wells and the deepening of old wells will probably add much information which is not now available, especially as to location of additional intermediate water sands around the edges of the field and the value of still lower oil horizons not yet penetrated.

Description of Figures

Fig. 35. Areal map of the Montebello Oil field.

Fig. 36. Map showing the topography of the field, enlarged from topographical map by United States Geological Survey.

Fig. 37. Underground contour map of top of first main oil sand of first oil zone.

Fig. 38. Underground contour map of top of intermediate edgewater sand. The sand carries water below the contour minus 2250 ft.

Fig. 39. Map showing wells producing from or penetrating various zones.

Fig. 40. An ideal graphic log of the productive oil zones in this field drawn to scale so that it may be applied in connection

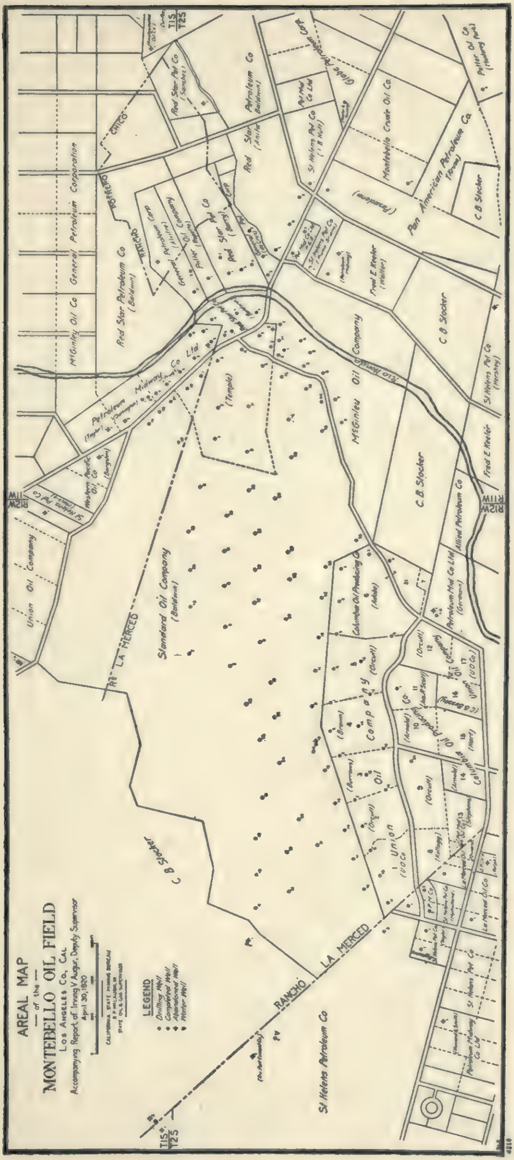


FIG. 35.—Areal Map of the Montebello Oil Field, California.

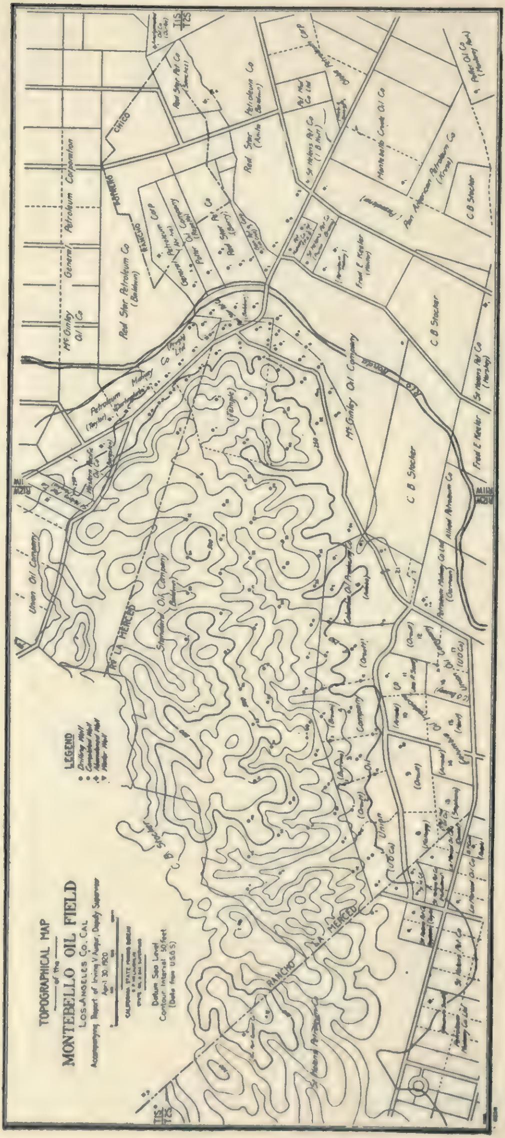


FIG. 36.—Topographical map of the Montebello Oil Field, California.

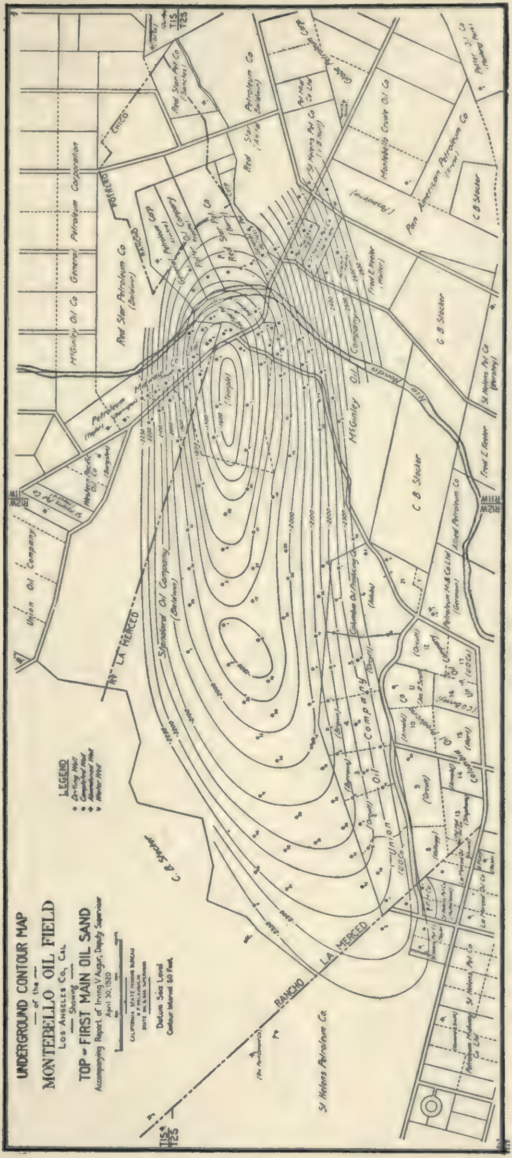


FIG. 37.—Underground contour map of Top Oil Sand of the Montebello Oil Field, California.

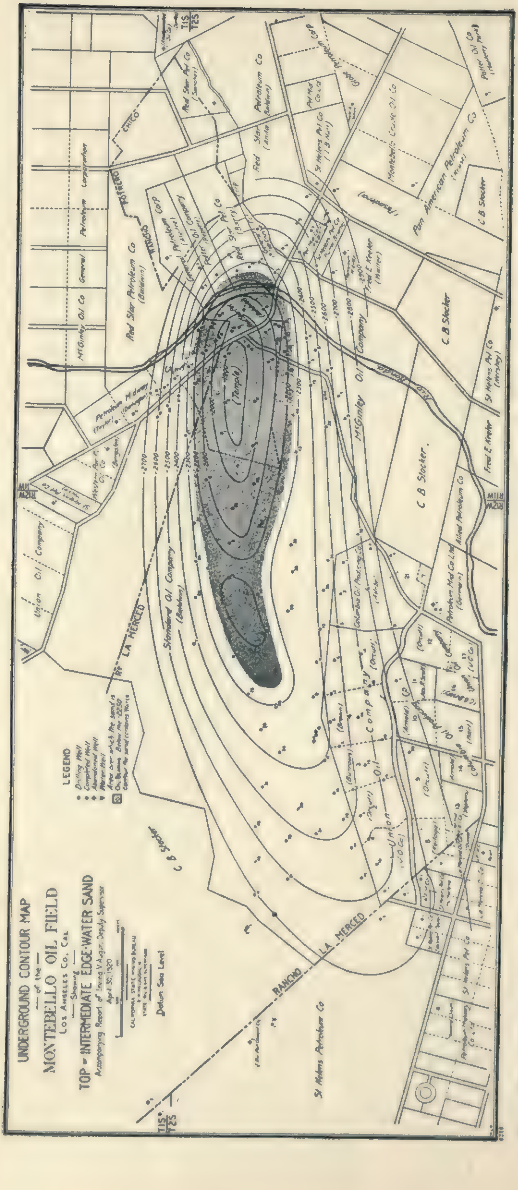


FIG. 38.—Underground contour map showing intermediate edgewater sand of the Montebello Oil Field, California.

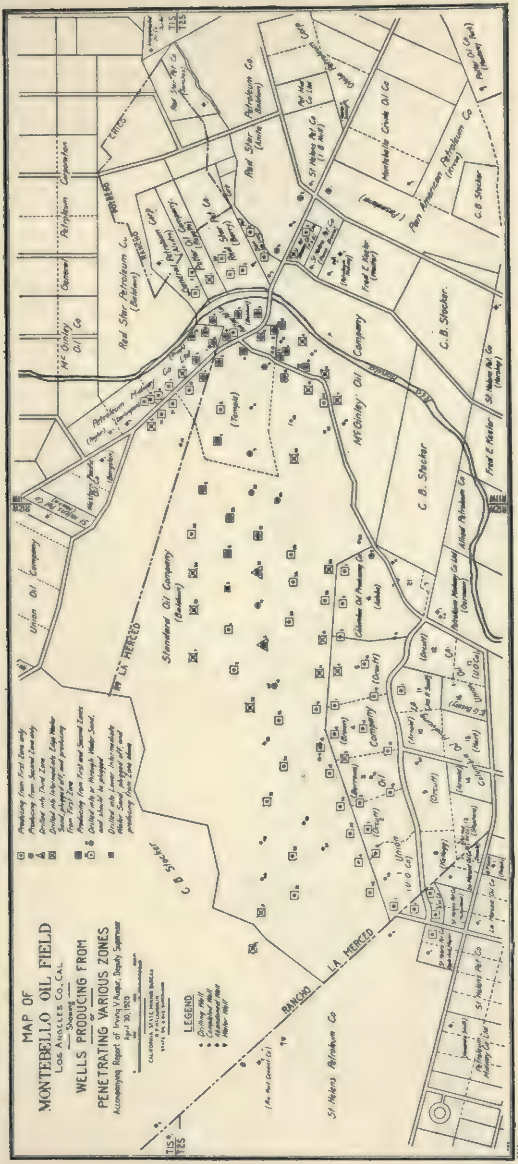
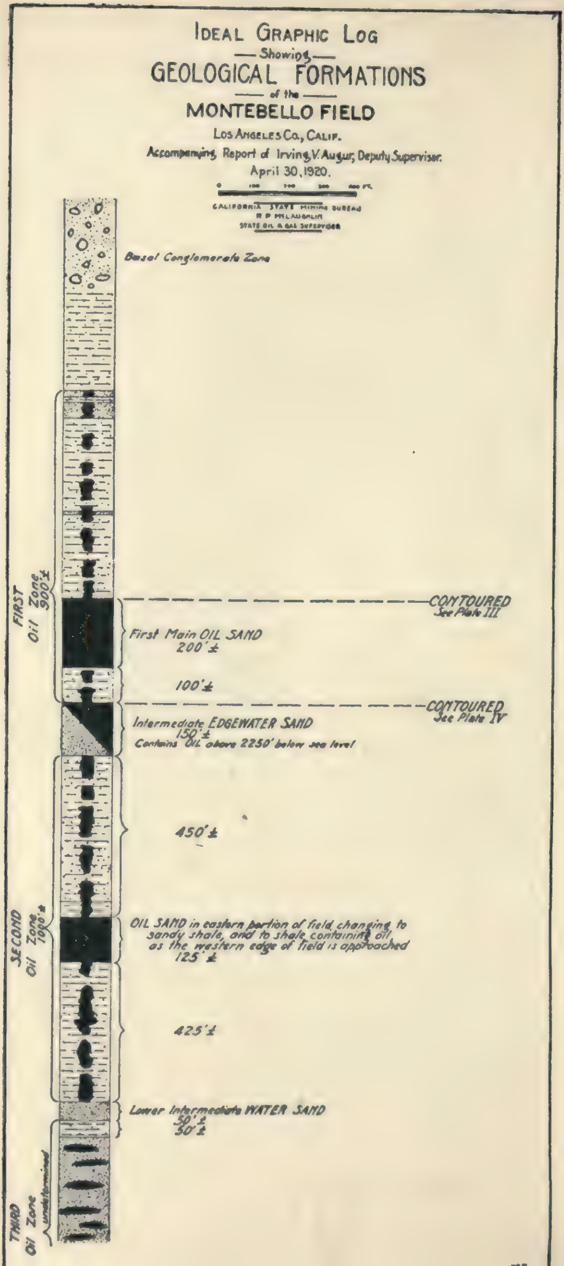


FIG. 39.—Map showing wells penetrating various zones of the Montebello Oil Field, California.



IDEAL GRAPHIC LOG
— Showing —
GEOLOGICAL FORMATIONS
— of the —
MONTEBELLO FIELD
LOS ANGELES CO., CALIF.
Accompanying Report of Irving V. Augur, Deputy Supervisor.
April 30, 1920.
CALIFORNIA STATE MINING BUREAU
R P McLAUGHLIN
STATE OIL & GAS SUPERVISOR
Basal Conglomerate Zone
FIRST Oil Zone 900'±
CONTOURED See Plate III
First Main OIL SAND 200'±
100'±
CONTOURED See Plate IV
Intermediate EDGEWATER SAND 150'±
Contains OIL above 2250' below sea level
450'±
SECOND Oil Zone 1000'±
OIL SAND in eastern portion of field changing to sandy shale, and to shale containing oil as the western edge of field is approached
125'±
425'±
Lower Intermediate WATER SAND
50'±
50'±
THIRD Oil Zone undetermined

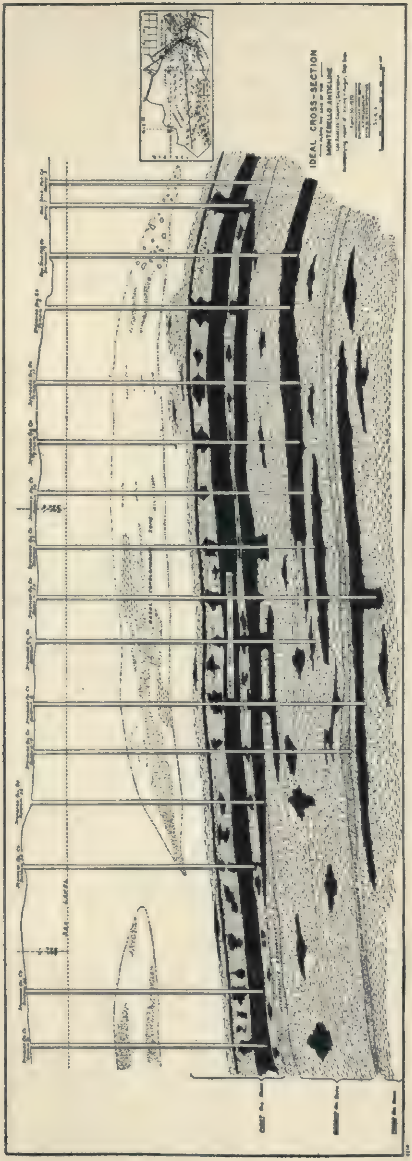


FIG. 41.—Ideal longitudinal cross section of the Montebello Oil Field, California.

with Figs. 36, 37 and 38 in determining in general the depths at which the various oil zones and water sands may be encountered at any particular location in the field. To apply the ideal graphic log, the elevation of the desired location should be secured from Fig. 36, and the depth to first main oil sand from

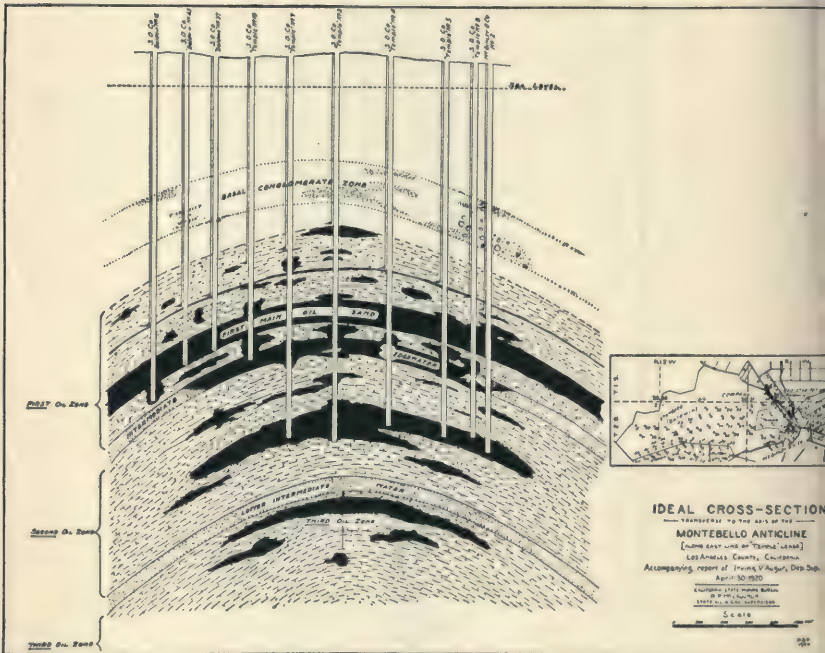


FIG. 42.—Ideal transverse cross section of the Montebello Oil Field, California.

Fig. 37. Then, by adding the intervals as shown on the ideal graphic log, the depth to intermediate edgewater sand, second oil zone, lower intermediate water sand and third oil zone may be figured. These figures will be general, and allowance should be made for increased thickness as the dip increases near the edges of the field.

Figure 41. Ideal cross section along the axis of the Montebello

anticline from east to west, showing the position of the various zones in the wells already drilled along such line. The section is reconstructed on the basis of the first main oil sand as an indicator and with the ideal graphic log as a guide.

Figure 42. Ideal cross section transverse to the axis of the anticline.

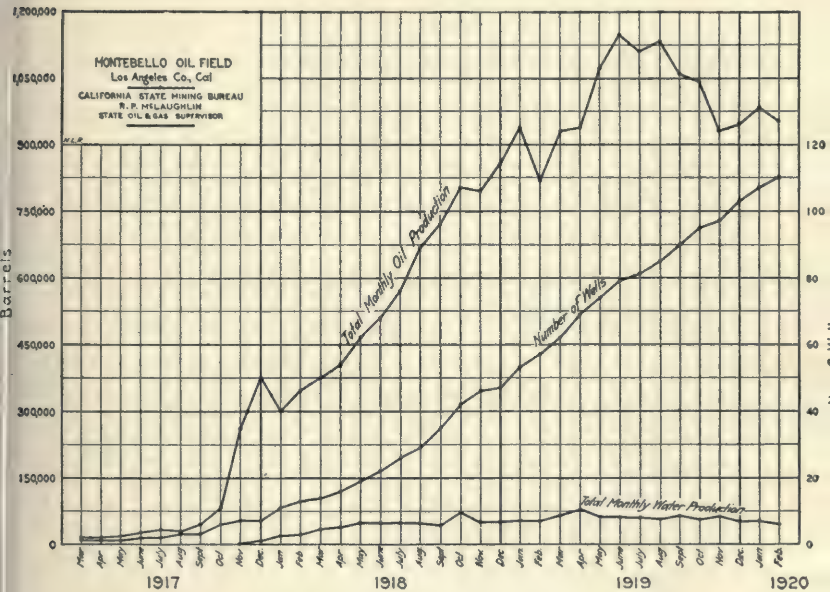


FIG. 43.—Diagram showing total monthly production of oil and of water. Montebello Oil Field, Cal.

Figures 43 and 44. Production charts showing graphically the production of the field from date of discovery to the present time.

Discovery and Importance of Intermediate Edgewater

Following is a brief summary of conditions and operations leading up to the discovery of the intermediate edgewater sand,

which sand has been the principal cause of water trouble in the field.[1]

A number of new wells, which had encountered what was termed "bottom," water had been plugged off at the bottom. The depth to the top of the last plug placed, where water was excluded was noted and a table made showing the interval between

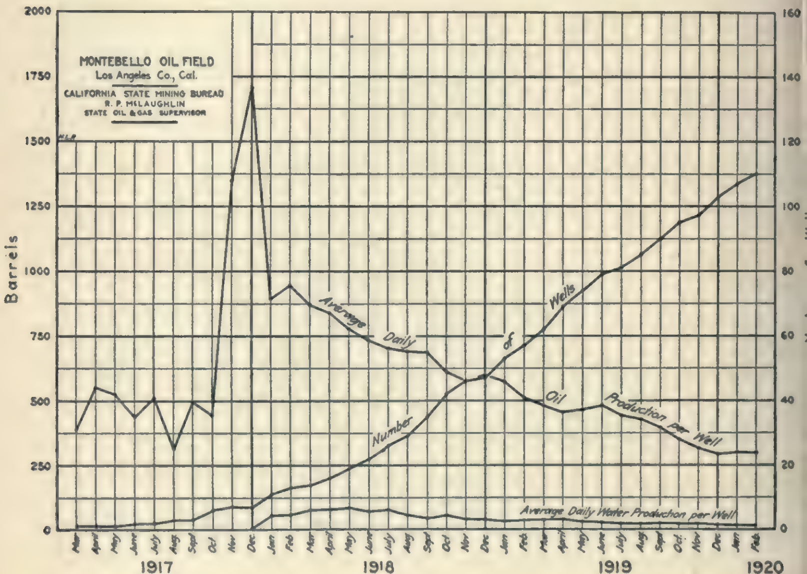


Fig. 44.—Diagram showing average daily production per well of oil and of water. Montebello Oil Field, California.

the first main oil sand and the supposed location of the water. This interval was in every case approximately 300 ft., allowing greater interval where the well was on the edge of the field due to increase in dip.

With the assistance of Mr. A. F. Davis, Superintendent of the Petroleum Midway Company, Ltd., an experiment was

[1] M. J. Kirwan: Montebello Field. Third Annual Report, State Oil and Gas Supervisor, Dec., 1918, p. 226.

tried in an endeavor to more closely determine the distance from the top of the first main oil sand to the top of this water sand. Water was shut off in their well No. "Baldwin" 5, Section 6, T. 2 S., R. 11 W., S. B. B. and M., some distance above the first oil sand, and the top of the sand logged as accurately as possible. Drilling was then continued about 130 feet below the top of the sand and the oil string was cemented. After cementing bailing test showed oil entering at the rate of about 3 bbl. per day. Drilling was then continued about 100 ft. further, perforated pipe was inserted and all fluid removed from the well. Bailing test showed oil entering at the rate of 6 bbl. and water ½ bbl. per day. The perforated pipe was then removed and drilling continued 50 ft. further. Perforated pipe was then set on bottom and the well was bailed to 1100 ft. and filled up to 690 ft. in seven hours with water. Water could not be lowered below 1417 ft. by sixteen hours of continuous bailing.

The results of this test showed definitely the presence of an intermediate water sand, as wells higher on the structure were producing clean oil stratigraphically deeper than this water sand.

It also demonstrated that this water sand was an edgewater sand, since those wells higher on the structure were producing clean oil from the identical horizon which produced water at this well. For this reason this water sand has been termed the intermediate edgewater sand. Upon examination of wells which encountered water in this sand, and comparison with wells which encountered oil in the same sand, it was not difficult to locate the line of edgewater.

McGinley Oil Company wells Nos. 3 and 4 are producing water and wells Nos. 1 and 5, only 300 ft. distant but up the dip, produce oil from the same sand. Following this edgewater around the field indicates that the line of edgewater apparently conforms very nearly to the minus 2250 ft. contour. It has definitely been proven that wells which tap this sand shallower than sea level minus 2250 ft., produce clean oil, while wells penetrating the sand lower than sea level minus 2250 ft. produce water. This creates a central dome around

the apex of the anticline which is free from this intermediate edgewater.

The following wells have been drilled through the first zone and into or just through the intermediate edgewater and have been plugged in the bottom so as to produce from the first oil zone.

Standard Oil Company.

No. "Baldwin" 11, Sec. 1, T. 2 S., R. 12 W., S. B. B. and M.
No. "Baldwin" 16, Sec. 31, T. 1 S., R. 11 W., S. B. B. and M.
No. "Baldwin" 19, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.
No. "Baldwin" 35, Sec. 1, T. 2 S., R. 12 W., S. B. B. and M.

Union Oil Company of California.

Nos. "La Merced" 3 and 4, Sec. 1, T. 2 S., R. 12 W., S. B. B. and M.

McGinley Oil Company.

No. 7, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Petroleum Midway Company, Ltd.

No. "P. & B." 1, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.
No. "Mulholland" 2, Sec. 2, T. 2 S., R. 12 W., S. B. B. and M.

Following is a list of wells, drilled into or through the intermediate edgewater sand, which are making water and should be plugged.

General Petroleum Corporation.

No. "Alvitre" 2, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Red Star Petroleum Company.

No. "Barry" 2, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

McGinley Oil Company.

No. 3, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

The following wells have been drilled into the second oil zone and plugged back, and now produce from the first zone only.

Standard Oil Company.

No. "Baldwin" 4, Sec. 2, T. 2 S., R. 12 W., S. B. B. and M.
Nos. "Baldwin" 10, 24, 25, Sec, 1. T. 2 S., R. 12 W., S. B. B. and M.
No. "Baldwin" 42, Sec. 2, T. 2, S. R. 12 W., S. B. B. and M.

Petroleum Midway Company Ltd.

No. "Prugh" 6, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

McGinley Oil Company.

Nos. 4, 6, Sec. 6, T. 2 S., R. 11 W.

Baldwin-Stocker Oil Estates.

No. 2, Sec. 2, T. 2 S., R. 12 W.

Potter Oil Company.

No. 1, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Standard Oil Company well No. "Baldwin" 29 was drilled into the second zone, later plugged and redrilled, and is now producing from first zone only.

No Provision made for Future Production

It is to be noted that nearly all wells drilled in the central dome, where the edgewater does not exist, are deep wells producing from both first and second zones. In these deep wells no provision has been made for encroachment of edgewater. This is due partly to the drilling policy which does not recognize the necessity for protection until water troubles appear and partly to the fact that underground conditions have become known since many of the deep wells were drilled. In new wells to be drilled to the second zone, in the central dome, account should be taken of the possibility of encroachment of edgewater as the oil is withdrawn from the intermediate edgewater sand, so that a change in casing program at a later date will be unnecessary. This might be accomplished by cementing an oil string below the first zone and intermediate edgewater sand, which at this point would carry oil, and producing from the second zone only until such time as this zone is exhausted, when the bottom of the well could be abandoned and production obtained from the upper zone, together with the edgewater sand, until edgewater began to appear in the edge sand which could then be plugged off. The possibility of producing from the third zone may suggest some other plans.

Under present conditions it would seem that the more oil that

is drawn from the edge sand in wells now penetrating same, the faster will be the encroachment up the dip in the direction of maximum with-drawal.

Drilling Policy in Zone of Edgewater

The policy for wells which are drilled outside of the central dome and in the zone of edgewater calls for a water shut-off above the first oil zone and a production from this zone only, unless a solid oil string is cemented above the intermediate edgewater and a second water string cemented below same to produce from the second oil zone and protect the first zone.

This program is, however, modified on the edge of the field where the first zone itself becomes edgewater or commercially non-productive, in which case a conductor string is landed near the surface; first oil zone and intermediate water are cemented off behind the next string of casing, after mudding formations under pressure and cementing the water string with sufficient cement to seal both intermediate water sand and first oil sand. Production may then be obtained from the second oil zone, which is commercially productive further from the axis of the fold than is the first oil zone.

The following wells have been drilled nearly to the base of the second oil zone, and being located in the zone of edgewater in the intermediate edgewater sand, were compelled to plug off the second oil zone and produce from the first oil zone only:

Standard Oil Company.

Nos. "Baldwin" 24 and 25, Sec. 1, T. 2 S., R. 12 W., S. B. B. and M.

No. "Baldwin" 43, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M

McGinley Oil Company.

No. 6, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Potter Oil Company.

No. 1, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

No assurance can be given that the second oil zone is protected from infiltration in these wells by the plugging operations.

The following wells have been drilled on the edge of the field and have cased off the first oil zone, together with the intermediate edgewater, on the basis that the first oil zone at such locations is commercially non-productive.

Red Star Petroleum Company.

No. "Barry" 4, Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Nos. "Baldwin" 2 and 9, Sec. 6, T. 2 S. R. 11 M., S. B. B. M.

Pan American Petroleum Company.

No. "Pasadena" 1, Sec. 6, T. 2 S., R. 11 W., S. B B. and M.

St. Helens Petroleum Company, Ltd.

No. "Monterey" 3, Sec. 2, T. T. S., R. 12 W., S. B 2 and M.

Columbia Oil Producing Company.

No. "Adobe" 3, Sec. 1, T. 2 S., R. 12 W., S. B. B. and M.

Production in the above mentioned wells is obtained the second zone only.

Lower Intermediate Water Encountered in Deep Wells

As briefly outlined above, drilling in this field is further complicated by the presence of a lower intermediate water-bearing formation below the second oil zone and between this zone and the third oil zone.

The lower intermediate water has been encountered in wells Nos. "Baldwin" 3, 6, 18 and 22 of the Standard Oil Company and to date the third oil zone has been encountered only in No. 22.

Only the four wells of the Standard Oil Company mentioned above have been drilled deep enough to encounter the lower intermediate water. The production of oil and the gas pressure are so high during initial production from the deep wells that in some cases the water does not immediately appear, but is very noticeable after decline in production.

Standard Oil Company No. "Baldwin" 3 has encountered and plugged off this lower intermediate water formation. No. "Baldwin" 6 produced clean oil at first, later produced as high

as 30 per cent water, and at the present time is sanded up in the bottom and water temporarily excluded.

Standard Oil Company well No. "Baldwin" 18 was brought in as a big producer. The water in the oil amounted to only .3 per cent. at that time, but since the production has declined and the gas pressure has been reduced, the percentage of water has risen to 11 per cent. and the well produces 3000 bbl. of water per month. An effort will undoubtedly be made, after the well ceases flowing, to plug the bottom of the hole and exclude the water.

Standard Oil Company well No. "Baldwin" 22 encountered the lower intermediate water, and its production was first obtained from the third oil zone only at the rate of about 1500 bbl. of oil per day. The lower intermediate water was also exposed in the well and water from this formation appeared in the initial production. Both third oil zone and lower intermediate water have been plugged off and the production is obtained from the second oil zone. In plugging off the water formation with the third oil zone, no assurance is given that the third oil zone is protected from infiltration.

Under present operating conditions it is practically impossible to penetrate and produce from all three oil zones or, except in the central dome, from more than one oil zone, in an individual well, due to the inclusion of one of the water formations under such conditions. It may, however, become mechanically possible at some time in the future to perform this feat, and the increased production which would be obtained thereby may justify the expenditure which would be necessary in experimentation to bring this about.

Production Data

Reference to production figures as reproduced in Tables 1, 2 and 3 and Figs. 43 and 44, shows the following interesting points as to the production of this field.

The production for the first year after discovery (1917) amounted to 922,926 bbl. of oil; production for the second year

TABLE 1.—TOTAL MONTHLY PRODUCTION, OIL AND WATER, MONTEBELLO FIELD

Month	1917		1918		1919		1920	
	Oil	Water	Oil	Water	Oil	Water	Oil	Water
January...	....	.....	303,452	18,615	939,082	52,909	982,812	51,395
February..	....	.....	346,207	21,175	816,281	52,284	956,659	45,050
March.....	12,060	13	379,223	33,000	931,135	65,329		
April......	16,524	16	404,871	37,168	942,153	76,564		
May......	16,298	0	459,195	48,221	1,073,702	61,670		
June......	25,560	0	509,546	48,610	1,144,206	61,342		
July.......	31,396	0	567,989	60,470	1,108,799	60,498		
August....	30,212	155	683,603	48,821	1,136,757	57,391		
September.	44,556	0	717,095	43,619	1,060,314	65,479		
October...	88,245	9	802,767	72,342	1,040,363	56,330		
November.	286,488	631	797,812	50,244	929,268	62,857		
December..	371,047	6,699	857,709	51,955	949,079	53,617		
Totals...	922,926	7,523	6,829,469	534,240	12,071,139	726,270	1,939,471	96,445

TOTAL PRODUCTION OF FIELD FROM DATE OF DISCOVERY TO MARCH 1, 1920

Oil, barrels..	21,763,005
Water, barrels..	1,364,478
Water, per cent......................................	5.9

(1918) amounted to 6,829,469 bbl. of oil; and production for the third year (1919) amounted to 12,071,139 bbl. of oil, or nearly one-eighth of the entire production of the state for that year.

The total production of the field for the past three years ending March 1, 1920, has amounted to 21,763,005 bbl. of oil, and the average percentage of water is only 5.9 per cent.

The maximum total daily production at any time since discovery occurred in the month of June, 1919, when the field was producing at the rate of 38,102 bbl. of oil per day. The total production at the present time amounts to approximately 33,000 bbl. of oil per day.

The maximum daily production per well, at any time since discovery, occurred in December, 1917, during which month the seven wells which were then completed produced at the rate of 1,706 bbl. of oil per day each.

On March 1, 1920, 110 wells were completed which produced a daily average of 299 bbl. of oil and 14 bbl. of water per well.

TABLE 2.—PRODUCTION DATA, MONTEBELLO FIELD, FROM DATE OF DISCOVERY TO MARCH 1, 1920

Month	Number of producing wells	Total daily production		Average daily production per well in bbl.	
		Oil	Water	Oil	Water
1917—March	1	388.3	0.4	388.3	0.40
April	1	550.2	0.5	550.2	0.50
May	1	524.8	0.0	524.8	0.00
June	2	851.1	0.0	425.5	0.00
July	2	1,028.3	0.0	514.1	0.00
August	3	972.8	5.0	324.2	0.17
September	3	1,483.7	0.0	494.6	0.00
October	6	2,841.5	0.3	440.2	0.05
November	7	9,540.1	21.0	1,362.9	3.00
December	7	11,947.7	215.7	1,706.8	30.81
1918—January	11	9,771.2	599.4	888.3	54.49
February	13	12,359.6	755.9	950.7	58.15
March	14	12,211.0	1,062.6	872.2	75.90
April	16	13,482.2	1,237.7	842.6	77.35
May	19	14,786.1	1,552.7	778.2	81.72
June	23	16,967.9	1,618.7	737.7	70.38
July	26	18,289.2	1,947.1	703.4	74.85
August	29	22,012.0	1,572.0	690.0	54.21
September	35	23,879.3	1,452.5	682.3	41.50
October	42	25,849.1	2,329.4	615.5	55.46
November	46	26,567.1	1,673.1	577.5	36.36
December	47	27,618.2	1,672.9	587.6	35.59
1919—January	53	30,238.4	1,703.7	570.5	32.15
February	57	29,141.2	1,866.5	511.3	32.75
March	62	29,982.5	2,103.6	483.6	33.93
April	69	31,373.7	2,549.5	454.7	37.01
May	74	34,573.2	1,985.8	467.1	26.84
June	79	38,102.1	2,042.7	482.3	25.86
July	81	35,703.3	1,948.0	440.7	24.05
August	85	36,603.6	1,848.0	430.6	21.74
September	90	35,308.5	2,180.5	392.4	24.23
October	95	33,499.8	1,813.8	352.6	19.09
November	97	30,944.6	2,093.1	319.0	21.58
December	103	30,560.3	1,726.5	296.5	16.76
1920—January	107	31,646.5	1,654.9	295.7	15.47
February	110	32,909.1	1,549.7	299.2	14.09

TABLE 3.—PRODUCTION OF MONTEBELLO FIELD, BY COMPANIES

Company	Total production to March 1, 1920		Average per cent. of water	Per cent. of water during February, 1920
	Oil	Water		
Standard	16,309,123	652,178	3.8	1.7
Union	1,957,397	149,472	7.1	11.7
Red Star	1,373,840	7,556	0.6	2.0
McGinley	915,746	254,715	22.1	7.6
Petroleum Midway	766,815	244,068	24.4	21.1
Columbia Oil Producing	289,878	24,092	7.6	14.6
General Petroleum Corporation	82,621	16,822	16.9	25.6
Pan-American	29,509	8,275	21.9	24.0
Potter	18,376	2,641	12.6	9.5
Baldwin-Stocker	13,618	4,432	24.6	21.8
St. Helens	6,082	227	3.6	3.8
Totals	21,763,005	1,364,478	5.9	4.5

From a study of Table 3, it will be noted that the percentage of water produced by the field at the present time is somewhat less than the average percentage of water for the entire production period. The decrease from 5.9 per cent. to 4.5 per cent. indicates a healthy state of affairs and although the production of individual small producing companies has shown an increase in water over the average, at the same time such companies are located on the edge of the field where water troubles become more aggravated, and the amount of production of the edge area up to the present time has been small, so that the production of the field as a whole has not been materially affected.

The total daily production of water for the field during February, 1920 was 1,649 bbl. Of this amount the Petroleum Midway Company, Ltd., produced 382 bbl. or 24.7 per cent. Out of the total of 382 bbl. for this company, 306 bbl. per day were produced by their well No. "Darlington" 1. The water production from this well, therefore, amounted to 20 per cent. of the total amount of water produced from the entire field and, if eliminated from this production, would reduce the percentage of water for the field at the present time from 4.5 per cent. to 3.6 per cent.

The above mentioned well is located on the northern edge of the field. The attention of the company was directed to the menace which this well constituted in February, 1919. At that time the company proposed to suspend repair work at the well pending the results obtained in drilling an adjoining well (No. "Darlington" 3) as to source of water. This proposal was approved and No. "Darlington" 3 has been completed. The work of plugging No. "Darlington" 1 is now in progress and it is expected that this well will be repaired, the water situation in this area greatly benefited, and the percentage of water for the field reduced.

Special mention should be made of the comparative absence of water from the production of the Standard Oil Company and Red Star Petroleum Company. The reduction in percentage of water for the Standard Oil Company from 3.8 per cent. (average percentage of total production) to 1.7 per cent. for February, 1920, is most gratifying and is an indication of the amount and character of the work this company has been carrying on in an endeavor to keep the production of their properties free from water. It will be remembered that the well which a year ago produced the greatest amount of water of any individual well in the field was located on the Baldwin lease of this company.

Gravity of oil Produced by Various Zones

The average gravity of the oil produced from the first or upper zone is 20° Baumé. This includes oil produced from the intermediate edgewater sand in the central dome, which at this point has been grouped with the first zone.

The average gravity of oil produced from the second zone is about 25° Baumé. It has been difficult, however, to obtain the average gravity of this zone, since wells which are producing from it are mainly in the central dome and are also producing from the first zone. The gravity of the oil in the second zone, as a whole, is apparently not uniform, the production from the upper portion being about 22° Baumé and from the lower portion about 28° Baumé. When the lower portion of this zone is produced with

the upper portion and first oil zone, a mixture is obtained which averages 25° Baumé.

The gravity of the oil in the third zone, from the evidence obtained at the single well which has produced from this zone only, is about 30° Baumé.

It is, therefore, apparent that in this field, generally, the gravity of the oil increases with stratigraphic depth.

In general, also, it is apparent that wells on the flanks of the anticline produce heavier oil from the same zone than wells nearer the apex. Following is a tabulation showing the gravity of oil produced by zones:

Zone	Number of wells	Average gravity	High	Low
First zone wells	67	19.5	23.2	16.2
First zone and oil from edge sand (pumping)	6	21.8	24.0	19.7
First and second zone wells—				
Flowing	18	23.3	26.0	20.2
Pumping	5	25.9	28.0	24.0
Second zone wells (only)	7	24.2	26.0	21.4
Second zone wells (flowing)	5	26.9	28.0	25.5
Third zone	1	30.2		

Conclusions

The results of the examination of this field show that on the whole the field is in very good condition, and as long as the individual oil zones are protected along lines used in the past, no unusual water troubles should develop.

In the three years which have elapsed since discovery of the field a total of 175 wells have been drilled or are now drilling. Of this number 112 wells are now producing, 30 wells are still drilling, 4 wells are idle and 29 wells abandoned. No dry holes have been drilled in the midst of proved territory and the wells which were abandoned were some of them located outside of the limits of the

field and are now known to have been drilled too far down the flanks of the anticline. Others were abandoned and a few are idle near the edge of the field and future development may indicate that an insufficient depth was reached to secure oil. At such locations drilling may be resumed with fair prospects of success.

During the past year the majority of the wells were completed to produce from the first zone only. The total production of the field has been declining because the production from the second zone wells has been declining more rapidly than the production has been augmented by new wells drilled in the first zone. With a more extensive campaign in drilling into the second zone, however, there is no reason to believe that the production of the field may not exceed somewhat the maximum past production.

It may be mentioned again that the second oil zone is productive much further from the center of the field than is the first oil zone. In fact, along the line where the first zone ceases to be productive, the production from the second oil zone amounts to from 500 to 1000 bbl. per well per day. Edgewater sands in the second zone itself will probably be encountered near the edge of the proved territory, which will tend to complicate the drilling program for this portion of the field and will call for very careful work in outlining the position of such sands and arranging the drilling to produce the greatest amount of oil with adequate protection.

It should also be borne in mind that the lowest portion of the second oil zone and also the third oil zone can not be counted upon to furnish much production near the edge of the field on account of the prohibitive depth of these formations and also the possibility of their carrying edgewater. The main production from these oil formations will undoubtedly be obtained in the central dome.

Recommendations

Following is a list of wells which contribute most of the water in this field, together with suggestions as to how such wells should be repaired.

General Petroleum Corporation

Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Well No. "Alvitre" 2.

This well has been drilled to a depth of 2590 ft., encountering sand in the bottom of the hole, logged as showing oil and gas. The percentage of water started off at 5 per cent. and gradually increased to 38 per cent. Study of sub-surface geology indicates that the well may have been drilled into the top of the intermediate edgewater sand and should be plugged in the bottom.

McGinley Oil Company

Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Well No. 3.

This well is finished at a depth of 3197 ft., penetrating about three-fifths of the second oil zone and also the intermediate edgewater sand which was not cased off. The well, therefore, started off with 26 per cent. water and is still making upwards of 30 per cent. water. Under date of March 19, 1919, a letter was sent to the company outlining the water situation at that time, and suggestions were made as to the repair of the well.

No work was commenced and on June 30, 1919, written recommendation was made that this company submit a proposal outlining necessary repair work, and stating that the source of the water had been identified as intermediate edgewater and offering the assistance of the department engineers in case suggestions were desired. After numerous discussions, delay of the necessary work was granted pending the results of plugging well No. 4, which shows a decided change for the better (see below) and it is recommended that plugging operations be started at this well (No. 3) without further delay.

Well No. 4.

This well was also drilled through the intermediate edgewater and into the upper part of the second oil zone, without protection from the water sand. Letter of March 19 and written recommendation of June 30, 1919, outlined the serious menace which

this well constituted and required that repair work start without delay. After considerable delay, a proposal was filed (September 4) for plugging the bottom of the well. This proposal was approved and the plugging has decreased the water content from 60 per cent to 20 per cent. Further plugging should be done to eliminate all or nearly all of the water.

Pan American Petroleum Co.

Sec. 6, T. 2 S., R. 11 W., S. B. B. and M.

Well No. "Pasadena" 1.—Reference to structural maps and sections indicates that this well cased off the first oil zone with the 8¼ in. casing and cemented above the intermediate water sand, necessitating the cementing of another water string. Production is obtained from the upper half of the second oil zone and has shown upwards of 25 per cent. water since completion. As soon as the well stops flowing as so to allow entering it, repair work should be started and the source of the water located by properly placed plugs. The water may be coming from an edge-water sand in the second zone or around the 6¼ in. water string, which could not be tested after cementing on account of the flow of oil.

Petroleum Midway Company, Ltd.

Sec. 31, T. 1 S., R. 11 W., S. B. B. and M.

Well No. "Darlington" 1.—As stated above, this well has been producing about 20 per cent of the water production of the field and is now being plugged in an effort to locate the source of the water and within a few montns will undoubtedly be greatly improved.

Sec. 2, T. 2 S., R. 12 W., S. B. B. and M.

Well No. "Mulholland" 2.—After finishing the well at a depth of 2750 ft. production amounted to 150 bbl. gross per day and 29 per cent. water and emulsion. Upon deepening 36 ft., salt water was encountered and the bottom of the well was plugged up to 2686 ft. reducing the water cut to 9.8 per cent. The percentage

has risen now to 26 per cent. and the water production amounts to 25 bbl. per day.

This water was undoubtedly encountered in the lower portion of the first oil zone and exists as an additional edgewater. The well should again be plugged in an effort to exclude the water.

Well No. "Mulholland" 3.—This well was completed in October, 1919, at a depth of 2687 ft., not deep enough to have encountered the water found in well No. 2 of the same lease. It is now producing 17 per cent. water. It is possible that this water is coming from well No. 2 and that, by plugging the latter well, this well might be benefited.

Red Star Petroleum Co.

Sec. 6, T, 2 S., R. 11 W., S. B. B. and M.

Well No. "Barry" 2.—It appears from a study of operations at this well that it is drilled nearly deep enough (2583 ft.) to have encountered the upper limit of the intermediate edgewater sand. Initial production contained 28 per cent. water, and this condition has continued to date. In order to benefit the oil production, it would seem advisable to plug the lower portion of the well.

Standard Oil Company

Sec. 31, T. 1 S., R. 11 W., S. B. B. and M.

Well No. "Baldwin" 16.—It is noted that this well produces more water than any other well operated by this company in this field and should therefore receive detailed attention. It appears that about 260 ft. of 10 in. casing was left in the bottom of the well without properly plugging before sidetracking. After sidetracking and continuing to the original depth, it was found that water had been encountered. The oil string was ripped and a cement plug was placed inside the casing and, although the production of the well was improved, water was not shut off.

The company then entered a proposal to continue plugging, and recommendations were made (March 6, 1919) regarding the

procedure to be followed, but nothing has been done in the last year in the line of carrying out the recommendations. The water trouble at this well is probably related to the water trouble in well No. "Darlington" 1 of the Petroleum Midway Company, Ltd. across the line, and now that work has started at the latter well, the well in question should be properly plugged and the water excluded from this area. The source of the water is apparently an edgewater sand in the lower portion of the first oil zone, similar to its occurrence in the western portion of the field.

SEC. 1, T. 2 S., R. 12 W., S. B. B. AND M.

Well No. "Baldwin" 35.—In drilling this well the upper portion of the first oil zone was cased off and production is obtained only from the lower portion, probably accounting for the small production as compared with adjoining wells. It was also drilled into the intermediate edgewater and produced upon completion 10 per cent. water and averaged for the first three months 21 per cent. water. Plugging up to 2650 ft. inside of the perforated oil string temporarily improved the water condition, but the well is now producing 44 per cent. water. It appears that the hole should be cleaned out to original bottom and the oil string shot and the bottom of the well more thoroughly plugged.

Well No. "Baldwin" 18.—Drilling was continued in this well through the first and second oil zones and into the lower intermediate water sand. The well at first flowed clean oil, probably on account of the high gas pressure. As the gas pressure reduced water began to show up until in December, 1919, the well was producing 11 per cent. or 3200 bbl. of water. This amount has now decreased to 9 per cent., and as soon as the well stops flowing the bottom should be plugged off.

UNION OIL CO.

SEC. 1, T. 2 S., R. 12 W., S. B. B. AND M.

Well No. "La Merced" 13.—This well has been drilled into the first zone only and at first produced 10 per cent. water. The

amount of water has now increased until it averages 40 per cent. or 4000 bbl. per month. It is noted that during the test of water shut-off, although the test appeared satisfactory, some mud fluid was returning into the well and it may be possible, because of this and the fact that the well has not been drilled into the intermediate edgewater, that water has broken in around the water string. Repair work should be started at this well without delay and the water excluded from the well as soon as possible.

CHAPTER 6

THE VALUE OF OIL LAND

The value of oil land depends upon the prospective profit to be obtained by extracting the oil.

In order to perform most efficiently special duties involved in the production of oil, each person in a producing organization should have a clear understanding of the ultimate purpose, profitable operation. The work of an oil producing organization should be divided among individuals who specialize upon certain features, but their specialization must not be carried so far that the individual workers will fail to co-ordinate their efforts with the general plan. Consideration of the elementary principles set forth in this chapter should assist in determining when to use and when to discard the details presented in the preceding chapters.

The three most important factors contributing to profit in producing oil are: (1) amount of oil available, (2) cost of extraction, and (3) market price. None of these factors are constant and therefore the value of a tract of oil land will change from time to time. The actual amount of oil under the surface may change owing to its migratory nature, and the amount of oil which can be extracted depends upon the degree of perfection of the operating methods employed. The cost of extraction will vary with changing prices of material and labor. Changes in the market price of oil are frequent.

Amount of Oil Available.—The amount of oil available in a tract of land can not be accurately estimated from facts which are observable before wells are drilled. Many factors which vary in different places enter into the determination of the oil content of land, such as thickness and porosity of the oil-bearing

formation, viscosity of the oil and gas pressure, all of which undoubtedly affect the amount of oil which can be extracted. These factors have not yet been systematically recorded and compared by operators to the extent necessary to the formulation of specific and satisfactory rules. Some or perhaps all of these factors have been observed in a general way, however by experienced oil men, and since they may serve as rough guides in estimating the amount of available oil they must not be ignored.

Business foresight demands not only an estimate of the total amount of oil available to extraction from a tract of land, but also the rate at which it can probably be extracted.

The constantly increasing magnitude of the oil industry has made it impossible to rely merely upon the judgment of experienced observers for estimates of oil content. An estimate of the amount of available oil is frequently used as the basis for many other calculations by different persons, and therefore it becomes necessary to present a foundation of definite and recorded facts upon which the estimate rests.

In the absence of any other definite index to future production it has been natural to turn to past records and use them as a guide. The features of past performance which have been most regularly recorded are gross productions from certain tracts of land during a series of years, or possibly even by months. These records may frequently be reduced to an average figure of production per acre, but such a figure is subject to some variation because it is impossible to determine exactly the area which has been drained. The number of wells from which the recorded amount of oil was obtained from time to time, has frequently been recorded and in some cases continuous records are found which show the production from each individual well. Therefore, the study of past performance can be narrowed to the consideration of production from single wells, or groups of wells.

It has been found generally that an oil well, after its very early stages, yields less and less oil as time passes. Comparison of

many records shows that, within a certain locality or field, the rate of decline in production follows some fairly definite rule.[1]

The rapidity of decline in production and the importance of considering and allowing for it is illustrated by the two curves shown in Fig. 45. Both curves represent wells in one of the California fields. Curve A[2] is constructed to show the actual

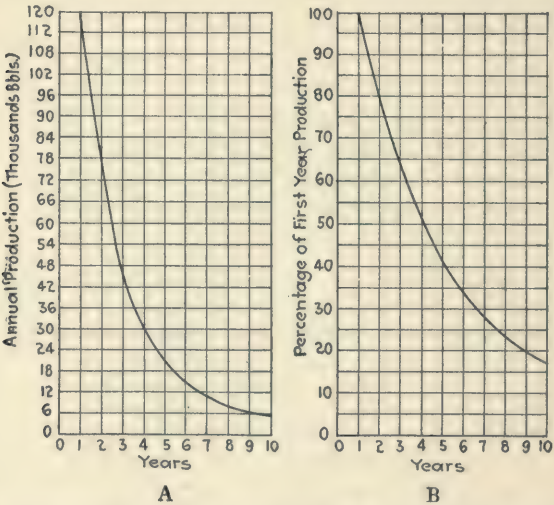


FIG. 45.—Curves showing decline in production of an oil well from year to year.

amounts of oil that a well may be expected to produce in any year, after the production of any given year is known. Curve B[3] is constructed to show the amounts of oil, expressed in

[1] The Decline and Ultimate Production of Oil Wells, with Notes on the Valuation of Oil Properties. CARL H. BEAL, U. S. Bureau of Mines, *Bulletin* 177, 1919.

Manual for the Oil & Gas Industry, Treasury Dept. U. S. Internal Revenue, 1919.

[2] C. H. BEAL and E. D. NOLAN, American Institute of Mining & Metallurgical Engineers, *Bulletin* 152, p. 1239, Sep., 1919.

[3] M. L. REQUA, American Institute of Mining & Metallurgical Engineers, Vol. LIX, p. 527, Feb., 1918.

percentage of the first year's production, that a well may be expected to produce each year after the first.

It will be noted that the two curves, A and B, are based upon different assumptions and give somewhat different results. The first curve (A) assumes that two wells producing equal amounts of oil, under similar conditions, will thereafter yield equal amounts of oil regardless of their respective ages. This assumption is in accordance with the fundamental principles governing the flow of liquids through orifices, and is therefore probably a correct basis for the compilation of such curves. However, it is important to note the limitation fixed by the words "similar conditions." Wells producing under exactly the same conditions are rare, and similarity of conditions may frequently be difficult to determine.

The conditions affecting the flow of oil from a well are numerous, and require detailed attention as set forth in the preceding chapters of this book.

In addition to the fact that the yield of an oil well constantly decreases, it has also been found that each additional well drilled into the common reservoir lowers the productiveness of its nearest neighbors. Furthermore, when completed wells become numerous enough, the later wells will have smaller initial yields than the earlier wells. Therefore, the study of performance of wells by neighborhood groups becomes necessary because the records of only a few wells might be exceptional and therefore misleading.

The average yield per well per day over a long period of time is a most significant basis for an estimate of future yield of oil. These figures can frequently be obtained from a study of records which show only the total production each year, month or day, from a given number of wells.[1] The average production per well per day is obtained directly from these figures. Its significance is easily recognized in the following diagrams which show gradual and regular decline.

[1] R. P. McLaughlin and C. A. Waring: Petroleum Industry of California. California State Mining Bureau, *Bulletin* 69, pp. 56–57, 1914.

These diagrams are so constructed that they clearly bring out many of the important operating features which have in the past affected a group of wells, such as the rate of development, and the periods of partial idleness. In many cases such diagrams will go far toward arriving at an estimate of the probable future

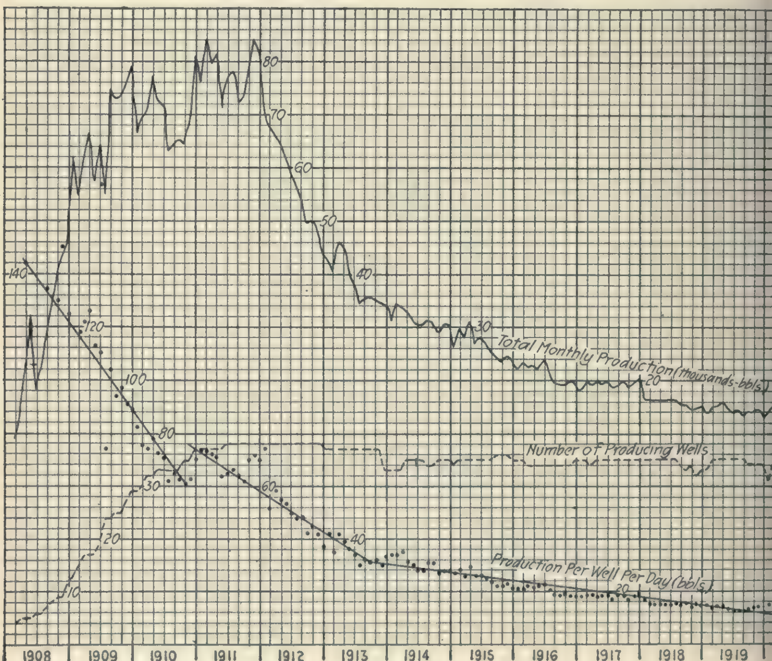


Fig. 46.—Graphic record of production of a small oil property (California).

yield of oil. It must be clearly borne in mind, however, that an accurate estimate requires inquiry into many details which will not appear upon mere production curves or diagrams.

Figure 46 shows the production history of a property which may be taken to serve as a basis of comparison in the examination of neighboring land. The property consists of 320 acres of proved oil land, underlaid by productive sands averaging 73 ft. in thick-

ness, and tapped by wells ranging in depth from 1124 ft. to 1949 ft. The oil is heavy, being about 15° Baume′. The property was systematically drilled and efficiently maintained. To the

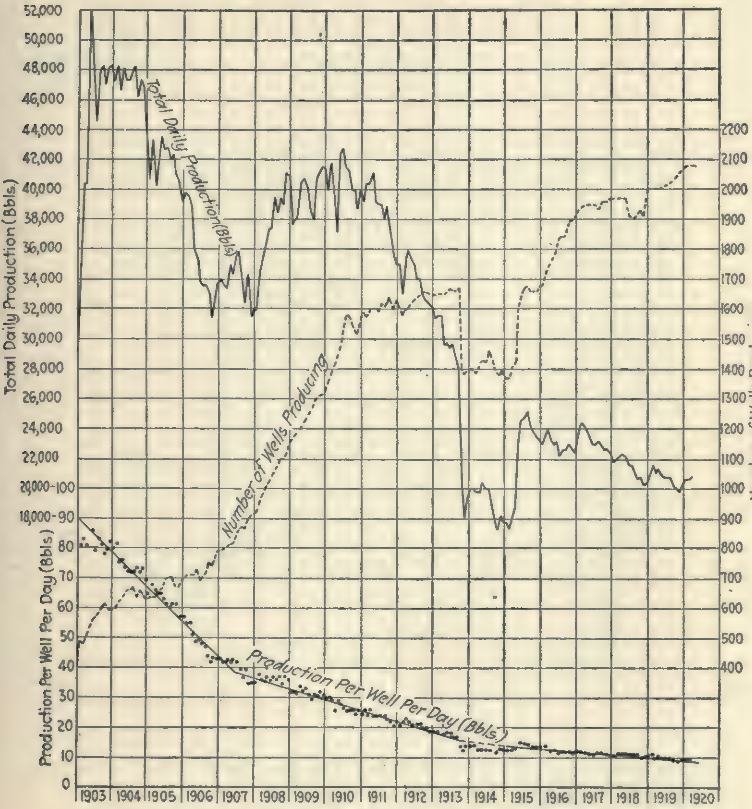


FIG. 47.—Graphic record of production of a large oil Field (Kern River, California).

west of this property the sands lie at shallower depths and are not commercially productive; to the east the sands are deeper, thicker and more productive, and greater operating obstacles are encountered, such as water. The property has produced 5,633,656

bbl. of oil, or an average of 17,570 bbl. per acre. Thirty-nine wells were drilled, of which four were non-productive either on account of mechanical difficulties or practically barren sands occurring.

Upon the basis of the two lines, one showing production per well per day, and the other number of producing wells, it is possible to make a reasonable estimate of future production.

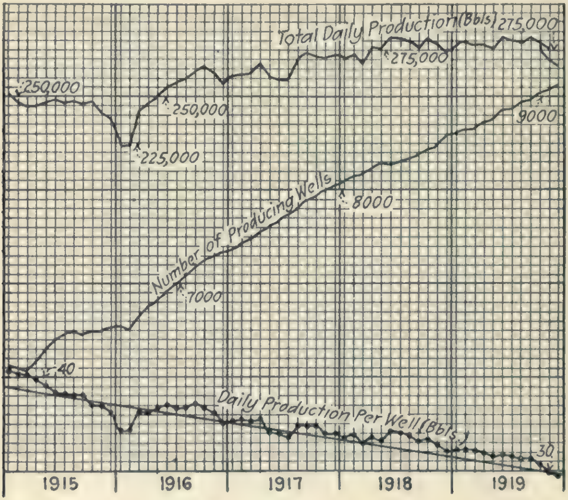


Fig. 48.—Graphic record of production of an entire state (California).

Figure 47 represents the Kern River field and shows that the same method of estimation applied to a single property can also be applied to an entire field after drilling and production have advanced far enough to furnish a basis.

The field comprises 6932 acres of proved land, underlaid by productive sands ranging from 250 ft. to 400 ft. in thickness with wells ranging from 700 ft. to 1100 ft. in depth. The oil is heavy, being about 14° Baume′. The field was not systematically drilled nor efficiently maintained, and water trouble has been great. The field has produced about 214,130,000 bbl. of oil or an average of 32,300 bbl. per acre. About 2250 wells were drilled, of

which about 175 were abandoned largely on account of mechanical difficulties or water trouble.

This method of estimation can be applied, with limitations, to very large groups of wells, as is shown by Fig. 48 which presents the production record of the entire State of California for a period of five years.

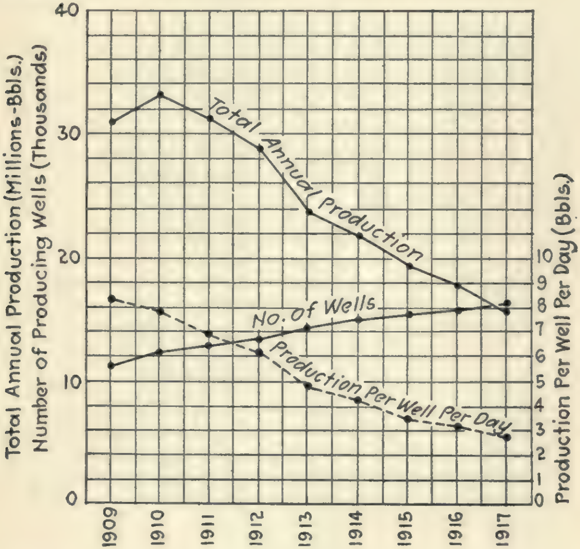


FIG. 49.—Diagram showing regularity of decline of production of oil wells in Illinois.

That the principle of regularity of decline of production applies to oilfields in general is shown by Figs. 49, 50, 51 and 52, which show the production records respectively of Illinois, Ohio Oklahoma and Pennsylvania.

"Settled production" has long been the basis for establishing the market value of oil properties. It is applied, as the name implies, after the initial or flush production has settled down to a somewhat uniform rate. A price per barrel of oil produced daily by a property is quoted as its value. The price per barrel for

settled production, at any locality, naturally varies with the market value of oil.

The fact that valuation upon "settled production" has long

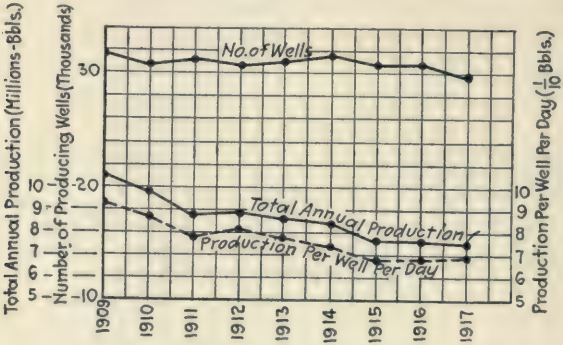


FIG. 50.—Diagram showing regularity of decline of production of oil wells in Ohio.

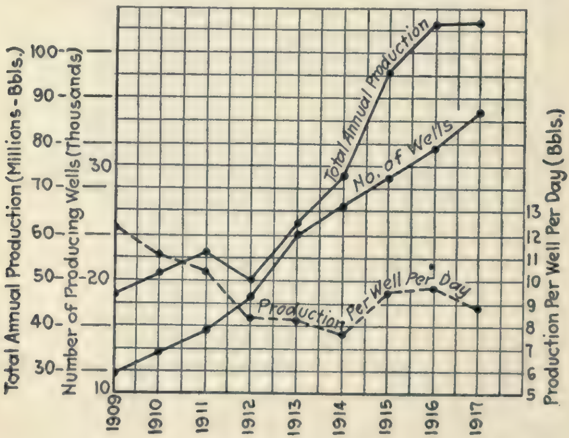


FIG. 51.—Diagram showing regularity of decline of production of oil wells in Oklahoma.

(NOTE: Decline interrupted in 1915 by opening of an extraordinarily productive new field.)

stood the test of commercial usage indicates that it is based upon principles which are sound. The six preceding diagrams showing the rate of decline in production per well per day, further estab-

lish the correctness of this method, and also furnish a means for its refinement and future usefulness.

The degree of saturation of an oil sand, together with its thickness, has been used in estimating the oil content of land. However, it is difficult, if not impossible, to determine either the degree of saturation or the percentage of recoverable oil; and furthermore, the thickness of sand is frequently inaccurately determined. This method seems principally useful in establishing a maximum limit beyond which the imagination of an optimistic estimator must not be allowed to stray.

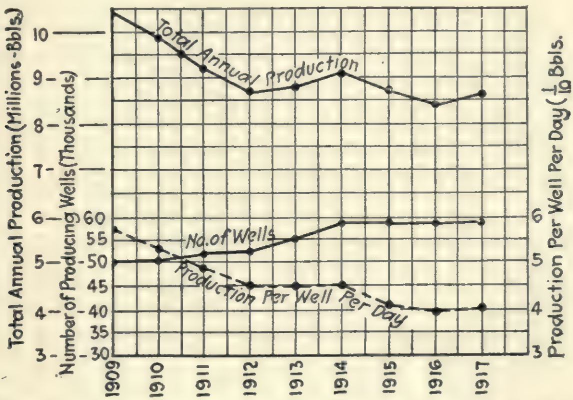


Fig. 52.—Diagram showing regularity of decline of production of oil wells in Pennsylvania.

Cost of Production.—Cost finding is an absolute necessity in the oil industry, as it is in all other industries. A properly devised system for determining cost of production serves two main purposes. First, the determination of the total cost per barrel of oil produced, which serves as a guide in determining at what price oil can be profitably sold. Second, the determination of the reasons for the existing cost, thereby furnishing a guide to enlarging profit through proper economies in production.

An operator who unwittingly forces production and sells his oil at a figure below its true total cost injures not only himself but his neighbors who are forced to meet his market price.

The subject of cost finding is so large that only the outstanding features can here be touched upon. No fixed rule will apply to all oil producing concerns or conditions, but the underlying principles are the same in all productive lines of industry. In order that a cost finding system may serve its two-fold purpose, it must be carefully devised by persons who are entirely familiar with the particular industry which is to be covered.

The cost records are, of course, a part of the general accounting system and must fit into that system, but they will sometimes be required to serve purposes that do not directly concern the accountant, and may therefore sometimes require less detail or precision than would be necessary for the accountant. The balance sheet is the exhibit toward which the accountant works,[1] while detailed costs are sometimes determined by independent investigations, the results of which may not necessarily be merged into the general accounts.[2]

The cost of oil production is usually contributed to by five main items (1) cost of land, or drilling right, either by direct purchase, or by lease involving bonus and royalty; (2) surface plant equipment, including buildings, tanks, roads and pipe lines; (3) construction or drilling of wells; (4) maintenance or operation of productive property; (5) general or overhead expense for management or supervision.

The first three general items represent the original outlay of capital which must be pro-rated through the accounts until the property has "paid itself out," or the capital has been returned. The period of time which the operator chooses to await the return or amortization of the capital expenditure, of course, depends upon his conservatism. It has been not uncommon, in some fields, to allow only three or four years. However, as the industry becomes more and more settled, and conditions are more carefully studied, longer periods of time will doubtless be allowed. The important feature to bear in

[1] Clarence G. Smith: Cost Accounting for Oil Producers. U. S. Bureau of Mines, *Bulletin* 158, p 6, 1917.

[2] Dexter S. Kimball, Cost Finding, Alexander Hamilton Institute, N. Y., 1917.

mind is that the deferred payments must be reckoned as items of regular production cost.

The use of cost figures may possibly be more clearly recognized if a complete preliminary estimate for the development of a property is presented here and followed later by more detailed consideration.

The estimate, here given, assumes that the property consists of 160 acres purchased at $1000 per acre. Conditions of the neighborhood justify an estimate that 20 wells will be necessary to drain the land (8 acres per well), and that a fairly reasonable estimate of production can be made by the methods previously mentioned. Wells to cost $20,000 each, and equipment (buildings, tanks, pipe lines, etc.) $40,000.

The plan of development contemplates the drilling of ten wells during the first year, and thereafter drilling enough wells each year to maintain a regular or constant total oil output. The capital investment would, therefore, be:

Land	$160,000
Ten wells	200,000
Equipment	40,000
Total	$400,000

Some operators might consider the subsequent wells as a part of the original capital, while others would follow the plan of considering them as an operating charge to maintain production.

Ten annual payments of $74,000 each would be required to replace the capital with 10 per cent. interest, the annual payments being reinvested at 4 per cent. compound interest. If the capital were merely returned without interest, that is, without profit, it would require an annual deposit, or fixed charge, of $33,316 at 4 per cent compound interest.

Under the conditions stated the property would doubtless produce for more than ten years at a profit above bare operating cost. Theoretically, one well might drain the entire tract of land if given time enough.

The complete estimate is as follows:

Year	Production, barrels		Expense			Cost per barrel		
	Total per year	Per well day				Operating overhead	Fixed	Total
1	135,000	...	Pumping 10 wells, av. 6 mos. (@$6 per well day).....	$11,000				
			Overhead (management, supervision, etc.)............	12,000				
					$23,000	$0.17	...	$0.17
2	450,000	123	Drilling 1 well.....	$20,000				
			Pumping 10 wells..	22,000				
			Overhead..........	12,000				
			Fixed charges (return of capital with profit)..........	74,000				
					128,000	0.12	0.16	0.28
3	450,000	112	Drilling 2 wells....	$40,000				
			Pumping 11 wells..	24,000				
			Overhead.........	12,000				
			Fixed charges......	74,000				
					150,000	0.17	0.16	0.33
4	450,000	95	Drilling 2 wells....	$40,000				
			Pumping 13 wells..	28,500				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					154,500	0.18	0.16	0.34
5	450,000	83	Drilling 3 wells....	$60,000				
			Pumping 15 wells..	33,000				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					179,000	0.23	0.16	0.39
6	330,000	68	Drilling 2 wells....	$40,000				
			Pumping 18 wells..	39,500				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					165,500	0.28	0.22	0.50
7	288,000	40	Pumping 20 wells..	$44,000				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					130,000	0.19	0.26	0.45
8	248,000	34	Pumping 20 wells..	$44,000				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					130,000	0.23	0.30	0.53
9	219,000	30	Pumping 20 wells..	$44,000				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					130,000	0.26	0.34	0.60
10	190,000	26	Pumping 20 wells..	$44,000				
			Overhead..........	12,000				
			Fixed charges......	74,000				
					130,000	0.29	0.39	0.68
11	160,000	22	Pumping 20 wells..	$44,000				
			Overhead.........	12,000				
			Fixed charges......	74,000				
					130,000	0.35	0.46	0.81
	3,370,000		Totals..........		$1,450,000	$0.21	$0.22	$0.43

Another method of distributing the repayment of invested capital is to charge off a fixed amount for each barrel of oil as it is produced. Such a procedure, in the case under consideration, would require $9\frac{1}{2}$ cents per barrel, and the total cost per barrel would appear more nearly uniform, as follows:

COST PER BARREL

Year	Operating and overhead	Fixed charges		Total
		Capital	Profit (10 %)	
1	$0.17	$0.000	$0.000	0.17
2	0.12	0.095	0.089	0.30
3	0.17	0.095	0.089	0.35
4	0.18	0.095	0.089	0.36
5	0.23	0.095	0.089	0.41
6	0.28	0.095	0.122	0.50
7	0.19	0.095	0.139	0.42
8	0.23	0.095	0.161	0.49
9	0.26	0.095	0.182	0.54
10	0.29	0.095	0.210	0.60
11	0.35	0.095	0.250	0.70

The profit or interest included in both of the foregoing distributions of cost assumes equal yearly payments. It might be desirable to distribute that item as a direct charge against each barrel of oil produced, in the same manner as the repayment of capital was just treated. Such a procedure would give a total fixed charge of 19 cents per barrel and the total cost each year would assume even greater uniformity, as follows:

Year	Total cost per bbl.
1	$0.17
2	0.31
3	0.36
4	0.37
5	0.42
6	0.47
7	0.38
8	0.42
9	0.45
10	0.48
11	0.54

The cost of drilling wells is in some fields fairly constant and requires but little study. Where wells are drilled by contract the operator is also relieved of the necessity of either making detailed estimates or systematizing an organization.

Where an extensive drilling program is contemplated, however, the cost of drilling has an important bearing on future profits. The problem is particularly important where drilling conditions are difficult and involve large expenditures. Cost figures should be collected and compared as a guide to reducing the drilling time and cost, and also for the purpose of perfecting the organization involved in the work.

A selection of items to be segregated is the first step in devising a cost finding system. The following outline has been found suitable to some extensive work and is presented merely as a suggestion.

Drilling Cost

- Derrick & Rig
    - Lumber, nails and bolts
    - Rig irons and bolts
    - Labor (building)
    - Shop work (wiring, etc.)
    - Teaming (while building)
- Engines & Boilers
    - Engine
    - Boilers
    - Pipe and fittings
    - Erecting
    - Belting
    - Tanks (fuel and water)
- Sump Hole
- Drilling
    - Labor (drillers, tooldressers, etc.)
    - Extra labor (rigging up, pulling casing)
    - Drill tools (bits, stems, jars, rope sockets, bailers, pipe tongs, spiders, slips, anvils, cranes, bit gauges, rental of tools, etc.)
    - Cordage (sand, drilling and casing lines, Manila cables, bull ropes, lagging, etc.)
    - Casing (cost or value of all left in well including that destroyed or lost)
    - General tools (hammers, sledges, wrenches, cutters, pipe threading tools, etc.)

Fuel and water
Repairs (engine, rig or boiler)
Oil, waste and packing
Sundries
Teaming (while drilling)

Fishing
Use and loss of tools owned
Rental and loss of tools rented
Labor

Cementing
Material (packer, box and rental or depreciation of pump)
Labor

Shooting
Material
Labor

Finishing
Labor (bailing, tubing, putting on beam)
Tubing
Pump and sucker rods

Cost of operating completed wells is, like drilling, sometimes so uniform as to require but little detailed accounting. Where large groups of wells are involved or where conditions are adverse, accurate cost finding is necessary. Conditions are more varied than those affecting drilling, and a general outline suiting all conditions is impossible. The following outline is suggestive of a plan for segregating items:

Pumping Cost

Motive Power Equipment
Engine (gas or steam), motor and transformers, power
Pipes (gas or steam), power lines, lines to jacks
Jacks or other equipment at well (not including pump or tubing)
Labor (installing)
Teaming (installing)

Operation
Labor (pumpers, firemen, etc.)
Fuel and water, gas or electricity
Lubricating oil, waste, packing
Miscellaneous

Repairs & Renewals
- Power plant
  - Labor
  - Materials
  - Teaming
- Wells
  - Labor (cleaning and redrilling)
  - Material
  - Teaming
- Pumps and rods
  - Labor
  - Material
  - Teaming

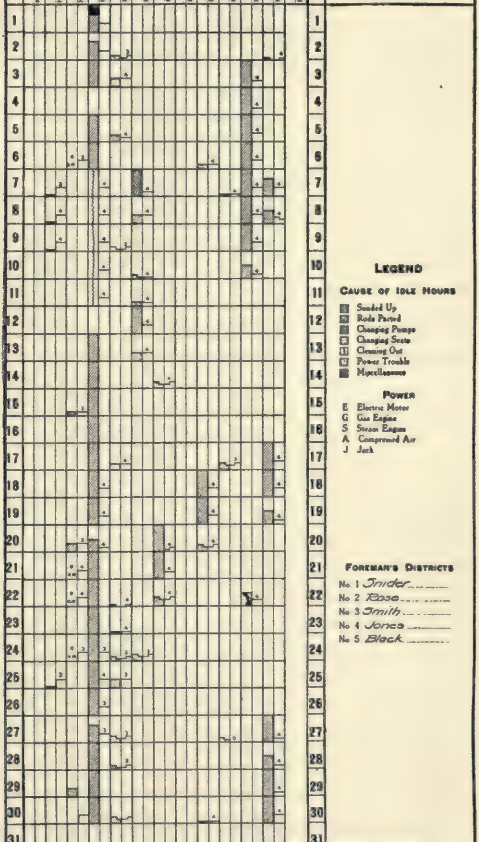
Accounting methods previously outlined cover capital expenditure and general operating cost, but absolute control of cost at producing wells would require a ledger account for each well and would involve too large an accounting force. However, it is sometimes advisable to assemble detailed information for the purpose of studying individual wells and determining whether each one is paying for its share of upkeep.[1]

Accounts of operation are frequently divided as follows:

1. Expense Production
2. Buildings & Fixtures
3. Water Service
4. Oil Storage & Deliveries
5. Power Plants
6. Insurance
7. Miscellaneous Expense

The addition or elimination of a few wells on a certain tract would make a change in the total expenditure in the first account (Expense Production). That account includes salaries of foremen and pumpers, expenditures for cleaning, pulling, repairing and redrilling wells, gas engines, motors and electrical equipment, steam engines and boilers. The salary expenses would not be altered by the addition or subtraction of a few wells. Therefore, a cost investigation involves only the segregation of the

[1] Graphic Methods of Maintaining Operating and Cost Statistics of Oil Wells. W. B. Blodget and H. L. Briggs. Fifth Annual Report, California State Oil and Gas Supervisor, Vol. 5, No. 9, March, 1920.



GRAPHIC RECORD OF PRODUCING WELLS

MONTH OF *November* 19*19* SECTION *37*

OPERATING STATISTICS

1	2	3	4	5	6	7	8	9	10	11	12	Well Number
1	1	1	1	1	1	1	1	1	1	1	1	Foreman's District
G	G	[illegible]	G	G	G	G	G	G	G	G	G	Power
8	2	8	24	24	24	24	24	24	24	24	24	Hours Pumped per Day
9	9	9	22	21	21	21	23	21	73	76	[illegible]	Avg. Daily Prod. Last Month
10	8	10	9	18	18	18	27	18	69	106	33	Avg. Daily Prod. Present Month

240	60	240	720	720	720	720	720	720	720	720	720	Total Hours Well Should Pump
0	8	20	649	54	[illegible]	60	0	59	2	192	173	Total Hours Idle
0	4	7	19	12	7	4	0	3	1	9	34	Total Days Worked Upon
0	0	0	19	0	0	0	0	0	0	0	0	Days Idle When No Work Was Done
0	19	19	50	22	18	10	0	13	0	31	17	Man Days of Labor
0	0	0	0	0	0	0	0	0	0	0	0	Cost of Power *Gas Supplied by the Well*
136	120	216	377	73	191	69	3	73	207	212	695	Total Cost of Operation *Labor & Material*
300	253	226	95	552	305	509	811	349	1997	2455	690	Total Production
453	476	956	3	657	.388	.1747	.004	.134	.119	[illegible]	.725	Cost Per Barrel

FIG. 53.

remaining items as they appear on time slips and storehouse receipts.

A convenient method of assembling the data graphically is shown in Fig. 53.

In describing the diagram Blodget and Briggs say:

"This plate presents in a clear, concise and graphic manner practically every bit of work done on a producing well. The tabulated data at the head of the sheet shows the location and number of each well, the foreman in charge, the pumping power, and the amount of oil pumped daily. The length of time the well is idle, and the cause, is platted, using symbols shown at the side of the sheet. The symbols actually used are colors, but because of difficulty of photographic reproduction they are here shown by different methods of cross hatching, which would be unsatisfactory in actual practice because of the amount of work it would entail. The time men worked on the well is shown graphically, and the small number above the platting shows the number of men in the gang. The data for platting are taken from a daily report made out by each production foreman, an example of which follows.

Production Foreman, Daily Report

Wells idle, 8; producing, 80; pumping test, 1; shut down, 3. Total, 92.

Well No.	Hours idle	Gang No.	Number of men	Hours worked	Remarks
6–25	2	4	3	2	Cut belts; repaired band wheel.
8–25	5	4	3	5	Rods parted; ran mouse-trap.
13–26	2	4	3	1	Changing grip-pipe.
1–36	O–H.W.	5	3	8	Running in tubing and rods.
4–36	1	Electric			Counter-shaft trouble.
16–36	24	C.O.	4	8	Cleaning out 40 ft. from bottom.
35–36	6	Gas engines			Repairing gas engine.
36–36	1	2	4	8	Sanded; pulling rods and tubing.

"At the end of the month each column is footed up and the cost per barrel calculated. It must be understood that this cost is not the total cost of producing a barrel of oil, but merely the cost of the direct charges of pulling, cleaning, etc. If the cost per barrel for that work exceeds or approaches very closely to the market price, the well should certainly be

repaired to increase its production, and if that is not possible, it should be abandoned. Of course, it may happen that the unit cost will run high for one month and low the next, and a period of about six months is required for a conclusive test before condemning the well for high costs.

"The comparison of monthly costs on one well over a long period involves the inspection of tabulated statements for the period under consideration, unless some graphic summary, by wells instead of by months, is provided. The data are summarized on the production charts, of which Fig. 54 is a sample. All of the information on this plate is of importance to a company executive and may be presented compactly and clearly by the graphic method.

"The calculation of unit costs of course assumes that a fairly accurate production record is kept on each well. The importance of this sort of data is becoming almost universally recognized. At the present time a more or less accurate record of every well should be available to the operator. The amount of production in some cases is obtained by setting a gauge tank at each well, and in other cases by pumping the oil from a group of wells into a tank and then pro-rating the group production to the various contributing wells. The first method is, of course, preferable from the viewpoint of accuracy, but fairly good results may be obtained by the second method if the performance of individual wells is closely watched, and an occasional test made with a portable gauging tank.

"Figure 55 shows an interesting possibility if the data previously discussed are available. The horizontal scale shows time, and the vertical scale shows dollars. Three lines are platted: (1) Accrued capital and operating cost of the well; (2) Accrued value of production at the well; (3) Operating cost. At the point of intersection of accrued cost and accrued revenue lines the well has paid for the work directly charged to it and is beginning to pay its share of overhead expense. If data were available a fourth line might be platted, representing total accrued cost of the well, including overhead, depreciation, interest on investment, etc."

Market Price of Oil.—A careful plan for the operation or development of oil land must consider the probable future market price of the oil. It is obvious that the subject is so large that present consideration can point out only general features and indicate sources of useful information.

GRAPHIC RECORD OF PRODUCING WELLS
PRODUCTION STATISTICS

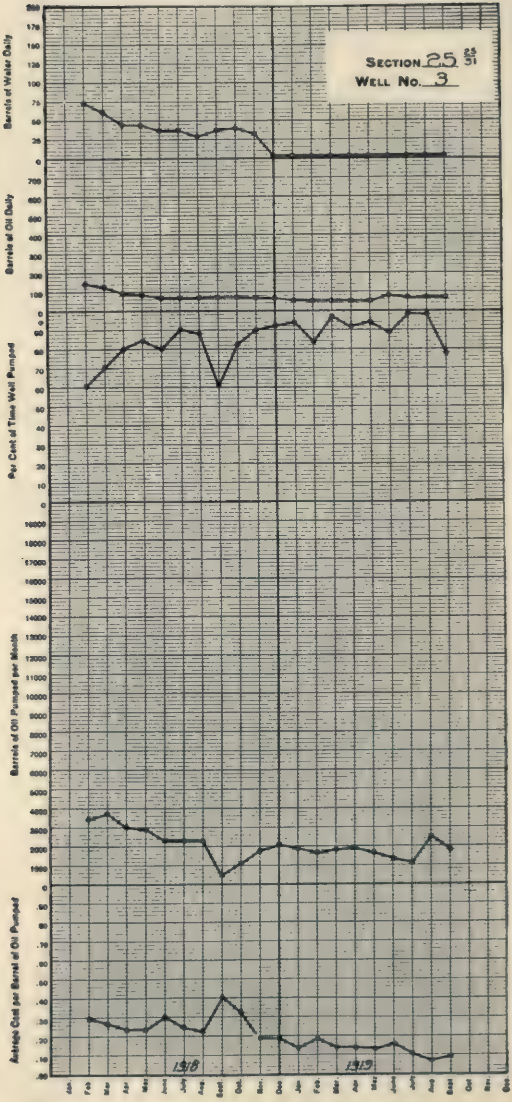


FIG. 54.

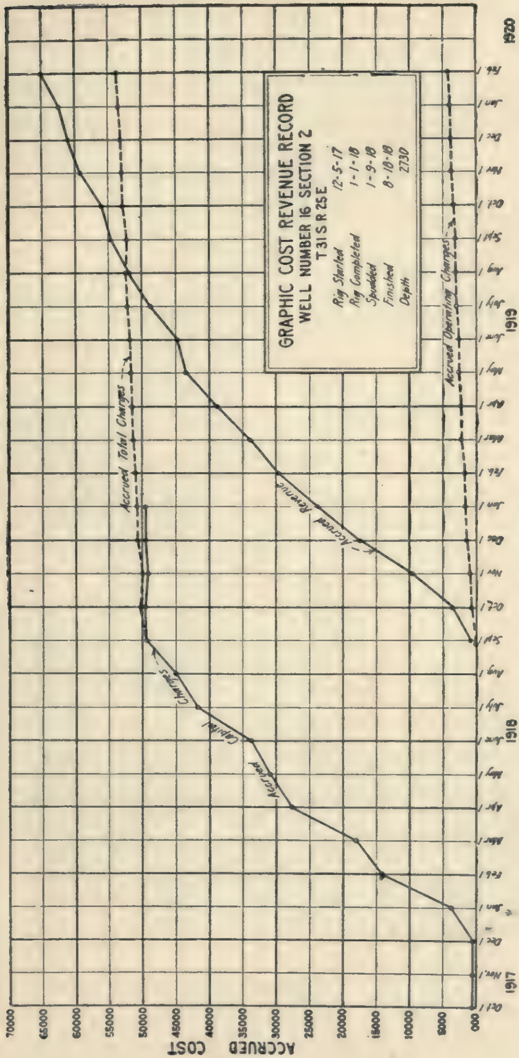

GRAPHIC COST REVENUE RECORD
WELL NUMBER 16 SECTION 2
T 31 S R 25 E
Rig Started 12-5-17
Rig Completed 1-1-18
Spudded 1-9-18
Finished 8-10-18
Depth 2730
Accrued Total Charges
Accrued Revenue
Accrued Capital Charges
Accrued Operating Charges
ACCRUED COST
1917
1918
1919
1920

FIG. 55.

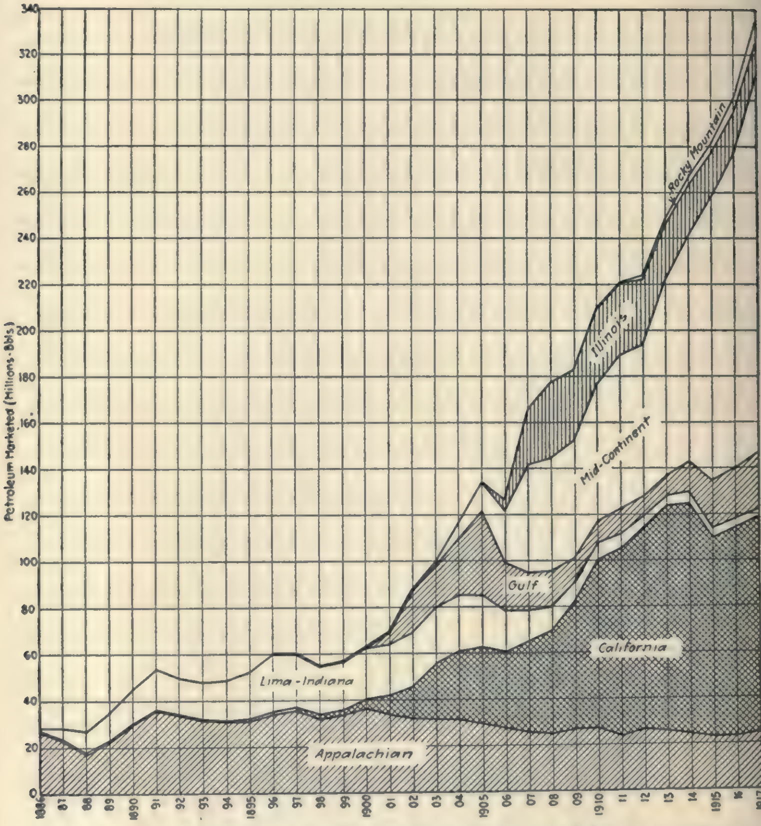


FIG. 56.—Oil production of the United States by major fields or provinces.

Supply and demand are, of course, the determining factors which result in market price. Stocks, or amounts of stored oil, represent in a broad way the resultant of the combined influences of production and consumption, and even under possible monopolistic control it appears that price movements of crude oil have been the same as under competitive conditions.[1]

The regularly published trade journals furnish current statistics of various fields, and the United States Geological Survey annually assembles or summarizes the results. Various state

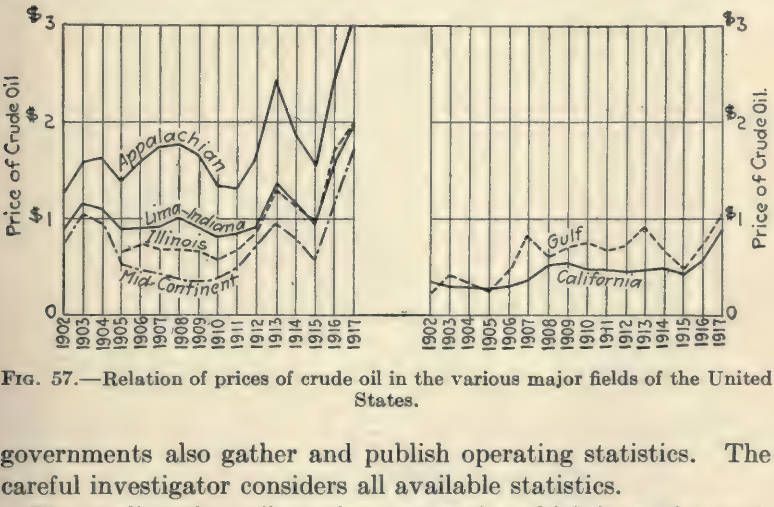


Fig. 57.—Relation of prices of crude oil in the various major fields of the United States.

governments also gather and publish operating statistics. The careful investigator considers all available statistics.

The quality of an oil, or the purpose for which it can be used, is a prime factor affecting its market value. The oil producing regions of the United States are conveniently divided into seven major fields or provinces, based upon the quality of oil. The amounts of oil marketed each year from the several fields are shown by Fig. 56.

Oils of somewhat similar characteristics may, to a certain extent, compete with each other where transportation and refining facilities are so developed as to afford interchangeability. This

[1] Report of the Commissioner of Corporations on the Petroleum Industry. Part 2, Prices & Profits, p. 114, Dept. of Commerce & Labor, August 5, 1907.

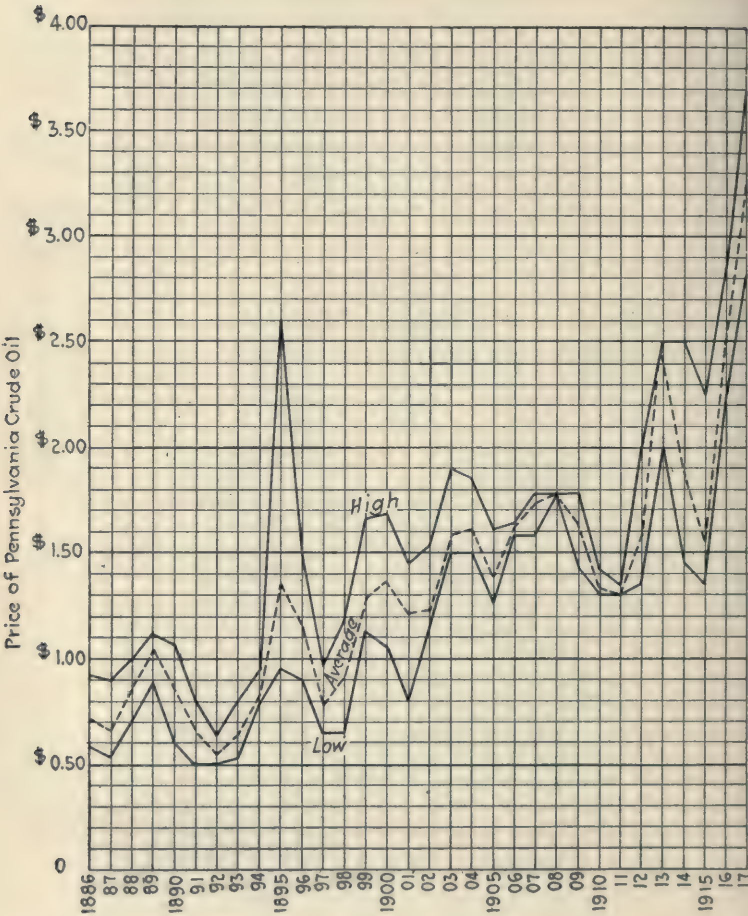


FIG. 58.—Annual variation in price of Pennsylvania crude oil. (Highest, lowest and average quotations, 1886–1917.)

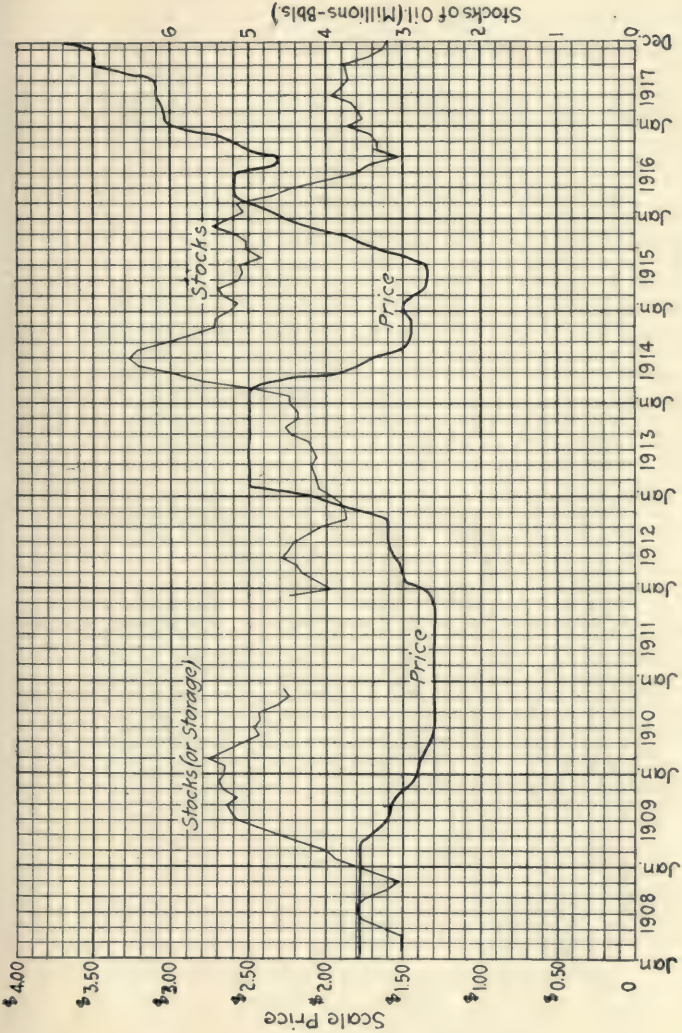


FIG. 59.—Relation of price of oil to the amount stored. (Pennsylvania crude.)

fact is shown in Fig. 57 with reference to the Appalachian, Lima-Indiana, Illinois and Mid-Continent fields. It will be noted that over some considerable periods of time the movements of prices are similar.

Oils which are of distinctly different characteristics, or are separated by geographic or commercial barriers, do not compete. Price movements of such oils are governed by other conditions and do not follow each other. This fact is shown in Fig. 57 with reference to the California and Gulf fields.

An estimate of probable market value of oil, therefore, requires a determination of what general field of comepetition it will enter.

Statistics showing the average annual price of oil within a single competitive field frequently will not afford sufficient information. There are sometimes sudden and violent fluctuations during a year. This condition is illustrated in Fig. 58, which covers Pennsylvania crude.

It is obviously impossible to formulate a rule for an accurate prediction as to the future price of oil. Constant and intimate touch with all market conditions is necessary. However, one indicator which is frequently used, among many others, is the increase or decrease of stocks of stored oil. The general relation existing between price and storage is shown by Fig. 59, which covers Pennsylvania crude by months for a period of ten years. It will be noted that prices and stocks generally move in opposite directions. It will also be noted, however, that the relative movements are only general, and that frequently the rule will not hold.

INDEX

Clarence O. Stee,
Valley City, N. Dak.
Feb. 28. 1922.